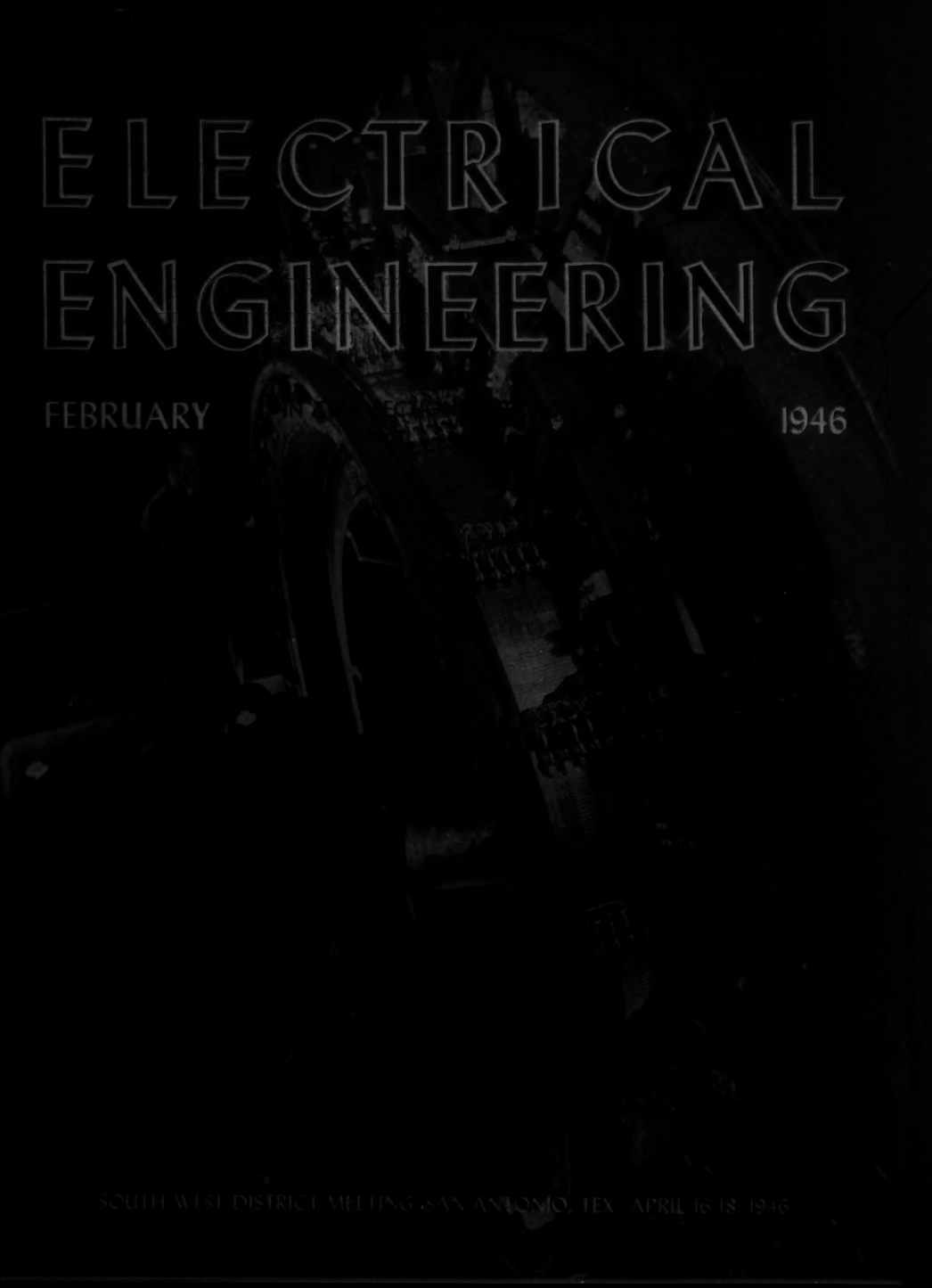
ELECTRICAL ENGINEERING

FEBRUARY 1946



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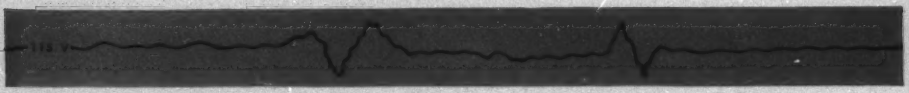

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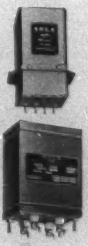

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1946

The Cover: A 7,000-horsepower steel-mill motor which can produce 19,000 horsepower at short-time peak output and is capable of reversing at base speed in less than two seconds.
Allis-Chalmers photo

Franklin's Role in Electrical Science.....Malcolm MacLaren . . . 57

Turbine-Electric Coast Guard Cutters . . . 65

Electric Measuring Instruments.....D. M. Nielsen . . . 66

Laboratory for Basic Electronics.....P. M. Honnell, W. E. Strohm . . . 75

Statistical Methods in Quality Control—IX.....AIEE Subcommittee . . . 81

Miscellaneous Short Items:
Original A-C–D-C Instrument, 80
Cambridge Mechanical Calculator, 83

Institute Activities . . . 84

Of Current Interest . . . 93

TRANSACTIONS SECTION

(Follows EE page 98; a preprint of pages 47–96 of the 1946 volume. Any discussion of these papers will appear in the June 1946 "Supplement to Electrical Engineering—Transactions Section" and in the 1946 volume.)

New Submersible Network Protector.....G. G. Grissinger, F. D. Johnson . . . 41

Solution of Attenuating Transmission-Line Problems.....George Glinski . . . 46

Electrical Measurements on Aircraft-Engine Ignition Circuits.Wm. E. Berkey . . . 49

Capacitor Stabilization of Transformers....J. H. Blankenbuehler, R. V. Lester . . . 54

Temperatures in Induction Motors.....C. P. Potter, A. E. Frohardt . . . 56

Circuit Breakers for 400-Cycle Aircraft System.....B. O. Austin . . . 58

Transients in A-C Motors and Generators.....George S. Smith . . . 61

Lightning Performance of Transmission Lines—II.AIEE Committee Report . . . 70

Combined Light and Power Systems for Industrial Plants...D. L. Beeman . . . 76

Effect of Altitude on Aircraft Electric Machines.....Cyril G. Veinott . . . 84

Electrical Analogy Methods..G. D. McCann, S. W. Herwald, H. S. Kirschbaum . . . 91

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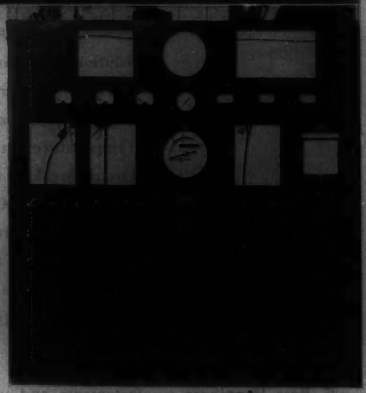

Labelled in Russian, this is one of eight boiler boards shipped as shown to U.S.S.R. Metermax Controllers and Micromax Instruments are mounted. Wiring for separately-shipped equipment can be seen, cabled and tagged, in cut-outs.

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HIGH LIGHTS . . . . . .

Production Delays. In terms of late issues, the January issue of *Electrical Engineering* set an unenviable record. Although schedules call for completion of mailing from the printing plant at Easton, Pa., by the fifth of the month, the January issue did not begin to go into the mail until the 21st. In addition to currently normal printing production delays, the paper supplied for the January issue turned out to be intermixed with sheets of substandard size which required hand-culling as they went through the presses and folders, to prevent the distribution of defective copies of *Electrical Engineering*. Some of these delays will carry over and adversely affect the completion of this issue.

Record Convention. With an as-yet-unverified total registration of approximately 2,500, the 1946 winter convention in New York, N. Y., easily surpassed the previous winter convention high mark of 1,931, which was established in Philadelphia, Pa., in 1941. A complete report of the convention is scheduled for March (*page 84*).

Nominees. J. E. Housley (F '43) nominee for AIEE president for the 1946–47 term, heads the list of candidates for Institute offices announced by the nominating committee (*page 84*).

1945 Indexes. The annual indexes to *Electrical Engineering* and *AIEE Transactions* for volume 64, 1945, are being distributed as section 2 of this issue, thereby marking resumption of a service that had to be foregone with the 1944 indexes because of paper restrictions. Although the regular indexes were produced for that year, copies were furnished only on request.

Circuit Breaker for 400 Cycles. Considerable thought is being given to the use of 400-cycle a-c systems in aircraft. A necessary device for such systems is a suitable circuit breaker; a lightweight 3-phase unit has been produced which performs satisfactorily in tests at atmospheric pressures corresponding to an altitude of 55,000 feet (*Transactions pages 58–60*).

Father of Electricity. For his contributions to electrical science Benjamin Franklin often is referred to as the father of electricity. Although there were some earlier investigations of electrical phenomena it is from the experiments and discoveries of Franklin and his contemporaries that modern theories of electricity are derived (*pages 57–64*).

West Point Laboratory. Of possible interest to other institutions planning facilities for instruction in electronics is the laboratory of the United States Military Academy, in which facilities are provided for as many as 140 students to conduct the same experiment, or for as many as 12 groups to conduct different experiments simultaneously with power supplied from central sources (*pages 75–80*).

January Cover. Astronomers and navigators among the membership were quick to chide *Electrical Engineering* for "reversing the heavens" in the picture carried on the January cover. Critics are correct, astronomically, but the cover nevertheless correctly pictured the refurbished decoration actually on the ceiling of main concourse of the Grand Central Station in New York City.

Acceptance Sampling. Much acceptance inspection is conducted on a sampling basis and, though some risks and errors are unavailable, systems incorporating various sampling methods have been developed which are suited peculiarly to certain types of inspection (*pages 81–3*).

Electric Measuring Instruments. Many recent developments in electric measuring and controlling instruments would appear to point the way to obsolescence for mechanical types of similar instruments. The electronic instruments undoubtedly possess advantages but they also have characteristics which make them impractical for some purposes. Further mechanical improvements probably will reduce the competition to one based on economic factors (*pages 66–74*).

Coast Guard Cutters. Thirteen turbine-electric a-c vessels will constitute the fleet of cutters now under construction by the United States Coast Guard. These vessels will have complete automatic control from the pilot house and either automatic or manual control from the engine room (*page 64*).

Letters. The use of glow lamps in a monitoring instrument for d-c motors and certain objections to recently issued reports on the impedances of synchronous machines are among the subjects included in the "Letters to the Editor" columns of this issue (*pages 95–7*).

Lightning Performance. Further data have been gathered on the lightning performance of 220-kv transmission lines to supplement a study first made in 1935. By means of a questionnaire, 13 companies participated in the present compilation of information (*Transactions pages 70–6*).

Industrial Systems. Introduction of fluorescent lamps operating on voltages higher than 120 volts for lighting industrial plants makes practicable the operation of combined lighting and power systems, with resultant economy (*Transactions pages 76–83*)

Correction. Due to a printer's error in the second line on page 24 of *Electrical Engineering* for January, "Statistical Methods in Quality Control—VIII," the expression $\bar{X}\times 530$ milligrams appears incorrectly. This expression should have read $\bar{X}'\times 530$ milligrams.

Network Protector. Low-voltage a-c network distribution systems require devices called network protectors to isolate the distribution transformers in case of faults. A new protector that is proof against submersion in case of flooding of its vault is designed for a continuous rating of 3,000 amperes and an interrupting rating of 40,000 amperes (*Transactions pages 41–6*).

News 84

Official Nominees 84
Planning Committee Secretary 84
1946 Winter Convention 84
1946 Summer Convention 84
Sections 85
Future Meetings
AIEE 84
Other Societies 95
Personal Items 85
Membership 91
Letters to the Editor 95
New Books 97
Pamphlets 98

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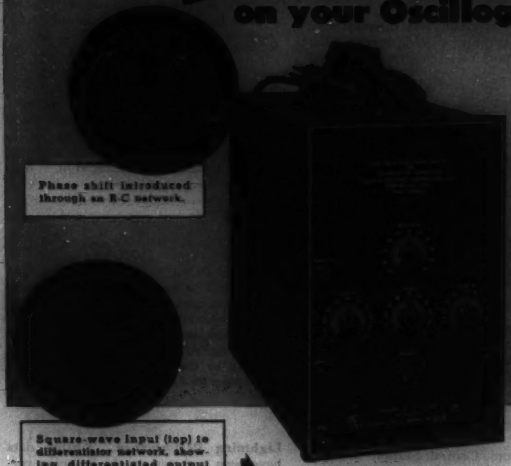

Phase shift introduced through an R-C network.

Square-wave input (top) to differentiator network, showing differentiated output (below).

The utility of any oscillograph can be greatly increased by operating it in combination with a Du Mont Type 185-A Electronic Switch!

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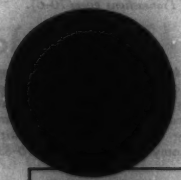
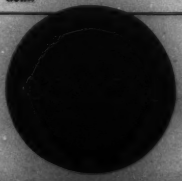


Sine-wave input (bottom) to full-wave rectifier showing rectified output (top).

Descriptive literature on request!

Comparison of input and output of phase inverter. Distortion in phase inverter is evident.



Sine-wave synchronization applied to the sawtooth output of a sweep generator.

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Along with the desire to save copper and eliminate lead sheaths, these considerations pointed to a continuous copper conductor of minimum cross section, a compact arrangement and a strong mechanical enclosure for the generator leads. This combination was found in Oilostatic in which oil-impregnated, paper-insulated cables are installed in steel pipes filled with oil at 200 p. s. i.

At Wilson Dam, the installation consists of 2 three-phase circuits up to 1670 feet in length, each phase consisting of a pair of 1,000,000 CM concentric strand shielded paper-insulated cables, all 6 cables being enclosed in a 7" o. d. steel pipe. At Kentucky Dam, there are 5 three-phase circuits up to 910 feet in length, each phase consisting of a pair of 1,500,000 CM compact segmental strand, shielded paper-insulated cables, all 6 cables being enclosed in a 8⅝" o. d. steel pipe.

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↑ Terminating structure of 13.8 kv Oilostatic Generator leads in transformer yard at Kentucky Dam, showing trifurcating terminal on pipe.

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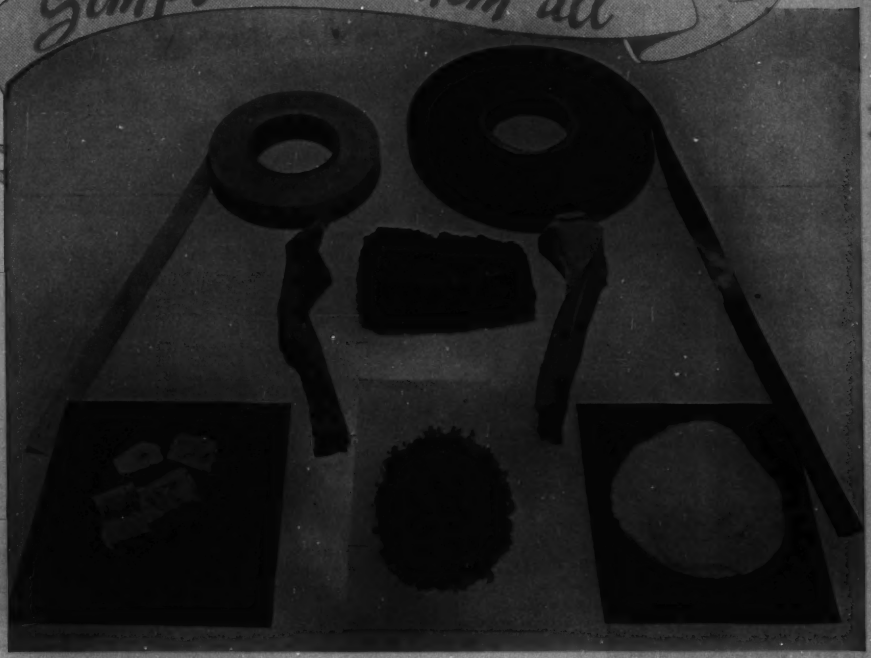

Whether it's the good old stand-by insulations, like varnished cambric or paper, or the very newest, such as polyethylene or silicone rubber, Simplex uses all of them in the places for which they are best adapted. Because Simplex has had wide experience with most of these insulations, it is thoroughly qualified to advise you on the engineering problems peculiar to cable construction and cable uses.

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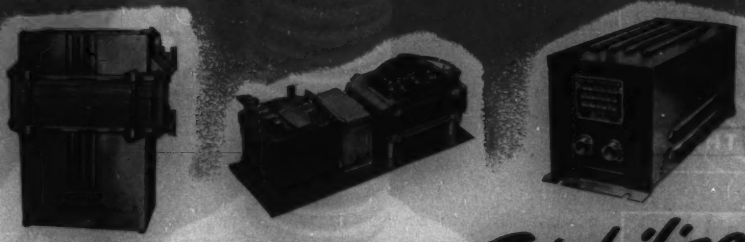

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Franklin's Role in Electrical Science

MALCOLM MacLAREN
MEMBER AIEE

WHEN BENJAMIN FRANKLIN drew the lightning from the clouds and identified it with the then little understood medium called "electricity," he initiated a movement that has led to untold blessings for mankind. The significance of this discovery was not so much in its intrinsic importance but rather in the unique personality of the discoverer and in the enthusiasm with which he carried on his studies in a field that up to that time had received little consideration from the scientific world.

In the light of our present knowledge many of Franklin's experiments seem quite trivial in character, and they impressed some of his friends in the same way. The wide range of his activities is illustrated by the interest he showed in early experiments in aviation. When questioned as to any possible use that could be derived from flying a balloon, he replied, "What is the use of a new-born baby?" He evidently had the same faith in the future development of the electrical industry, which was his major scientific interest, and possibly he made the same reply to those who questioned his interest in this field for in the later years of his life he frequently was called the father of electricity.[1]

Benjamin Franklin was born in Boston, Mass., on January 17, 1706, into a family of 17 children, 7 of whom were children of his father's first wife. Benjamin was the youngest son in this large group and he had the unusual distinction of completing a direct succession of youngest sons through five generations. His formal education was limited to only two years of conventional school instruction and at the age of ten Benjamin became an assistant to his father who was a tallow-chandler and soap-boiler. In this business he was employed in cutting wicks, filling candle molds, and acting as general errand boy for the establishment.

Living in the port of Boston where ships arrived from all parts of the world, and being galled by the confining nature of his work, Benjamin was tempted strongly to abandon his home for a seafaring life. However, his brother James arrived from England with printing press and equipment that enabled him to build up a business as printer and publisher and Benjamin acquired a new interest. He was apprenticed to James and served with him until he was 17 years old. Here he became an expert typesetter and began his career as a writer, though he later confessed that his early attempts "were wretched stuff in the Grub-street ballad style."

Prior to the 18th century little serious scientific interest had been aroused by electrical phenomena. However, when Benjamin Franklin, in 1746, began experimenting with electrical effects he initiated much productive activity in the field and, in fact, in later years was known as the "father of electricity." This article presents a discussion of early electrical discoveries by Franklin and his contemporaries. Excerpts from letters and publications then current afford an insight into scientific thought of the period.

Benjamin's business relations with his brother were not always peaceful and after many disputes he left James and boarded a ship for New York in order to be entirely free from his influences. He arrived in Philadelphia, Pa., in October 1723 after crossing New Jersey, largely on foot. He came without any knowledge of the town and with only a few shillings in his pocket but with his trade as a profession he readily found employment. His genius for making friends soon became apparent and within a year after his arrival he had acquired many among whom was Sir William Keith, the governor of the province, who took him under his patronage. It was at Keith's suggestion that Franklin made his first visit to London where he remained for two years.

Upon his return to Philadelphia Franklin resumed his profession as publisher. Through his writings, and by his industry and good sense, he became the recognized head of journalism in the Colonies. In 1731 he established the first circulating library in America. The next year he started his "Poor Richard's Almanack" which was continued for 25 years and which attained great popularity and wide circulation.

In 1736 Franklin began his political career by becoming a member of the General Assembly. At about this time he organized the first police force and fire department in the Colonies and provided for the paving of the principal streets in Philadelphia. A few years later he was active in movements for starting a hospital, for founding the American Philosophical Society, and for establishing an academy which later became the

Essential substance of "Early Electrical Discoveries by Benjamin Franklin and His Contemporaries" which appeared in the *Journal* of the Franklin Institute, volume 240, July 1945.

Malcolm MacLaren was professor emeritus, Princeton University, Princeton, N. J., at the time of his death on September 24, 1945 (*EE, Nov '45, p 415*).

University of Pennsylvania. It was not until 1746 that he first became interested in the study of electricity. He described how this occurred in the following words:

"In 1746 being in Boston, I met there with a Doctor Spence, who had lately arrived from Scotland, and he showed me some electric experiments. They were imperfectly performed, as he was not very expert; but being a subject quite new to me, they equally surprised and pleased me. Soon after my return to Philadelphia, our library company received from Mr. Peter Collinson, Fellow of the Royal Society of London, a present of a glass tube, with some account of the use of it in making such experiments. I eagerly seized the opportunity of repeating what I had seen in Boston and by much practice acquired great readiness in performing those, also, which we had an account from England, adding a number of new ones. I say with much practice for my house was continually full, for some time, with persons who came to see these new wonders.

"To divide a little this incumbrance among my friends I caused a number of similar tubes to be blown in our glass-house, with which they furnished themselves, so that at length we had several performances. Among these, the principal was Mr. Kinnersley, an ingenious neighbor, who being out of business, I encouraged him to undertake showing the experiments for money, and drew up for him two lectures, in which the experiments were arranged in such order, and accompanied with explanations in such a method, as that the foregoing should assist in comprehending the following. He procured an elegant apparatus for the purpose, in which all the little machines that I had roughly made for myself were neatly formed by instrument makers. His lectures were well attended, and gave great satisfaction; and after some time he went through the colonies, exhibiting them in every capital town, and picked up some money."[3]

As has been noted previously it was not until Franklin's day that scientists began to take a serious interest in electrical phenomena. However, it would be appropriate to consider briefly what electrical discoveries had been made up to that time. It long had been known that certain bodies, later called nonconductors, could receive an electrical charge through friction. This charge could be detected either by a prickling sensation produced by contact of the charge with one's body or by bringing the charge into the presence of shreds of silk, paper, or other light material. These first would be attracted to the surface of the charged body and, after coming in contact with that surface, they would be repelled from it. It also was known that these light objects, when charged from different sources, behaved in an uncertain manner when brought close to each other. In some cases there was an attraction between them and in others a repulsion. When they received their charge from the same source they always were repelled. This discovery led to the development of the first electric instrument which was known as an electroscope. This electroscope took various forms but one of the best known consisted of two strips of gold leaf inclosed in a glass bottle. They were suspended from a common metal terminal which extended through the neck of the bottle so that when a charged body was brought into contact with the terminal its presence was indicated by a separation of the gold leaves.

In 1729 Stephen Gray, a member of the Royal Society of England, made experiments to determine the difference in the behavior of conductors and nonconductors for transmitting an electrical charge. He used lines of silk, iron, and brass which gradually were extended to a length of about 900 feet, and he employed a brass-leaf electroscope as a detector.[3]

At about the same time Charles Francois de Cisternay du Fay, a member of the Royal Academy of France, developed his two-fluid theory of electricity. He had noticed the afore-mentioned capricious action of charged bodies, namely that in some cases such bodies were attracted to each other while in other cases they were repelled. He explained this action by the principle that there were two kinds of electricity. One, which he called vitreous electricity, could be produced by friction upon glass, rock-crystal, precious stones, hair of animals, wool, and many other bodies. The other he called resinous electricity. It was produced from amber, copal, gum-lack, silk, thread, paper, and a vast number of other substances.[4]

In 1745 the Leyden jar or phial was developed, so named through the work of Pieter van Musschenbroek, professor of philosophy and mathematics at the University of Leyden. He had observed that electrified bodies soon lost their charge when exposed to the air and conceived the idea that more stable conditions could be obtained if he could devise means for enclosing the charge in a nonconductor. He partly filled a glass bottle with water while his assistant held it in his hand. During the manipulation of the circuit when it was being charged the assistant received a telling shock in his hand and arm which clearly demonstrated the effectiveness of the device. William Watson, a member of the Royal Society of London, brought the jar into its modern form by coating both the inside and outside of the jar with metal.[5]

The development of the Leyden jar provided means for producing much stronger electrical effects than previously had been possible. Also, more powerful generators were designed so that the way was paved for a considerable advance in the study of electricity. This was reflected by a great increase in the number of papers recounting experiments in electricity that were appearing in the technical papers, especially in England and France. Martin Folkes, president of the Royal Society of London, made the following comment on this situation:

"Electricity seems to furnish an inexhaustible fund for inquiry and such phenomena so various and so wonderful, can arise only from causes very great and extensive, and such as must have been designed by the Almighty author of nature for the production of very great effects."[6]

William Watson in England and others on the continent of Europe found that light spirits could be ignited by an electrical discharge and that visible sparks could be seen that were accompanied by sounds resembling a

miniature thunderstorm.[7] Watson then started a study of the electrical conductivity of different substances that was continued for several years. He pointed out the difference in the behavior of conductors and non-conductors and showed that metals were best for conducting a charge. In 1747 he made a true electrical transmission experiment. He laid a wire across Westminster Bridge in London and stationed an observer on each bank of the river. The observer on the Westminster side held one terminal of the wire in one hand and made contact with the river by inserting an iron rod which he held in his other hand into the water. The observer on the Surry shore took hold of the wire with one hand and grasped with his other a large phial filled with iron filings and coated with sheet lead highly electrified from a glass globe installed in a neighboring house. A third observer, standing near the second, dipped an iron rod which he held in one hand into the water while he touched with his other hand the iron hook of the phial which made contact with the iron filings. As soon as this contact was made the charge snapped and was felt by each of the three observers. This experiment was repeated several times with equal success but during the progress of the tests a large crowd of spectators had collected on the bridge and had caused considerable annoyance by breaking the transmission wire and in other ways interrupting the experiment. The total length of the circuit, including the water, was about 2,400 feet.

Watson decided to continue these tests but in order to avoid interference from a curious audience he moved his equipment into the open country. He varied his experiment by using an overhead wire for his outgoing circuit and a bare wire laid on the ground for the return circuit. Starting with a total length of line of about one mile, he gradually increased this to nine miles and received signals successfully in each case. He then made an attempt to determine the velocity of the electrical transmission. A gun was fired at the far end of the line at the same moment that a charge from a Leyden jar was introduced into the circuit. The difference in the time between the reception of the charge and that of the sound of the gun was noted and knowing the velocity of sound it was estimated that the velocity of transmission of the electrical charge was practically instantaneous compared with that of sound.[8]

While Watson was conducting these transmission experiments he also was making many others in order to obtain more specific information regarding the properties of electricity. He finally concluded that what we call electricity is a very subtile and elastic fluid common to all bodies which in their natural state have the same electrical density, that this fluid manifests itself only when bodies capable of receiving more than their natural share are operated upon by certain well-known methods, and that they show their electrical condition by attracting or repelling light objects, by a snapping sound, or by sparks, and in fact may be capable of affecting any of our senses. Watson also concluded that no snapping is observed when two bodies have the same density, that the intensity of the snapping is determined by the difference in the density of the two objects, and that certain bodies which he called electrics have the essential property of transmitting electricity.[9]

Within a year from the time that Franklin began to be interested in the study of electricity he received, from Europe, his first recognition as a scientist. The first reference to his scientific work to appear in the *Philosophical Transactions* was given by William Watson in the paper referred to in the foregoing. He stated that Mr. Collinson recently had received a paper concerning electricity from an ingenious gentleman, Mr. Franklin, a friend of his in Pennsylvania. The paper was dated June 1, 1747. By a curious coincidence which sometimes occurs in scientific investigations, two students, entirely without knowledge of each other's work, covered much the same ground but did not always reach the same conclusions. In this case, while Watson was carrying on his research in London, Franklin was making his experiments in Philadelphia. He gave his results in the paper which he sent to Mr. Collinson and which was presented to the Royal Society. Franklin designated the two electrical states that a body might receive as the result of a positive or negative charge, terms that have continued in use to the present day.[10]

In July 1747 Franklin investigated the effect of different forms of terminals upon the discharge of a Leyden jar. For one terminal he used a cast iron shot about four inches in diameter. When he approached this with the other terminal which consisted of a sharply pointed bodkin the discharge took place through an air gap of six to eight inches. If he substituted a blunt body for the bodkin, the terminals could be brought to one inch of each other before the discharge took place.[11] This experiment later guided Franklin in the design of the terminals for his lightning rods.

It was about this time that Franklin began his study of lightning with the definite purpose of identifying it with electricity. Other scientists had noted that the vivid flash accompanied by a crackling sound which occurred on the discharge of a group of highly charged Leyden jars was quite suggestive of a flash of lightning followed by thunder. At about this same time Abbé Jean Antoine Nollet, professor of physics at the University of Paris and member of the French Academy, a prolific writer on electrical matters, expressed the hope that someone would attempt to prove that thunder in the hands of nature is what electricity is in ours and that the wonders which we now exhibit at our pleasure are but little imitations of those effects that frighten us.

In the spring of 1748 Franklin wrote to Peter Collinson describing experiments he had made on charging and discharging Leyden jars and in studying the effect of grouping them in different combinations. But he

appeared to be rather discouraged at the futility of this work for he closed his letter with the following paragraph:

"Chagrined a little that we have hitherto been able to produce nothing in the way of use to mankind and hot weather coming on, when electrical experiments are not so agreeable, 'tis proposed to put an end to them for the season, somewhat humorously in a party of pleasure on the banks of the Skuylkil. Spirits at the same time are to be fired by a spark sent from side to side through the river, without any other conductor than the water—an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by the electric shock, and roasted by the electric jack, before a fire kindled by the electrified bottle, when the healths of all the famous electricians in England, Holland, France, and Germany are to be drank in electrified bumpers, under the discharge of guns from the electrified battery."[12]

Answering a letter from this same English friend he wrote later in 1748 expressing his pleasure on hearing that the paper which he had presented the previous year had met with the approval of the Royal Society and also that his ingenious friend Mr. Watson was preparing another paper on the same subject. He stated that he himself lately had been doing very little experimental work in electricity but that he hoped to take it up again during the following winter, "as the approaching peace gives us a prospect of being more easy in our minds."[13]

Franklin's reference to hostilities concerned an early stage in the French and Indian war with the Colonies, and while his hope for an early peace was not realized he did find time to resume his electrical studies. In the summers of 1749 and 1750 he wrote to his English friend, Peter Collinson, giving him many examples of the way in which lightning produced effects similar to those from a heavily charged Leyden jar. He also suggested a theory to explain how clouds, as they collected before a storm, might draw electricity from the earth. He confessed, though, that he would not place too much reliance upon this theory and then made the following comments:

"It is not of much importance to us to know the manner in which nature exerts her laws; 'tis enough if we know the laws themselves, 'tis of real use to know that china left in the air unsupported will fall and break; but how it comes to fall and why it breaks are matters of speculation; 'tis a pleasure indeed to know them, but we can preserve china without it. Thus in the present case, to know the power of points in assisting in the discharge of Leyden jars may be of some use to mankind in preserving houses, churches, ships, and so forth, from the strokes of lightning by directing us to fix on the highest parts of those edifices, upright rods of iron made sharp as a needle and gilt to prevent rusting and from the foot of those rods, a wire down the outside of the building into the ground, or down around one of the shrouds of a ship and down her side till it reaches the water."[14]

This appears to be the first time that Franklin had given an account of his famous lightning rod which soon came into wide usage, not only throughout the Colonies, but also in Europe, and since that time has been of inestimable value in the protection of property.

Franklin then went on to describe an experiment for proving definitely whether or not lightning was an electrical discharge. This later became known as the Philadelphia experiment and as it created a real sensation in the scientific world of that day, Franklin's description of it is given in full:

"To determine whether the clouds that contain lightning are electrified or not, I propose an experiment to be tried where it may be done conveniently. On the top of some high tower or steeple place a kind of sentry-box big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass bending out of the door and then upright for 20 to 30 feet, pointed very sharp at the end. If the electric stand be kept clean and dry a man standing on it, when such

Franklin Institute mural painted by Thornton Oakley

clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from a cloud. If any danger to the man should be apprehended (though I think there should be none), let him stand on the floor of his box and then bring near to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle, so the sparks if the rod is electrified, will strike from the rod to the wire and not affect him."[15]

When Collinson showed Franklin's letter to other members of the Royal Society they ridiculed his theory and said that it was not worthy of publication in their *Transactions*. However, in the following year a short and very guarded note by William Watson was published

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in the *Transactions* in which Watson said that Franklin had a very thorough knowledge of electrical matters, that he had the head to conceive and the hands to execute his experiments, but that he held some few opinions with which Watson could not agree.[16]

In the summer of 1752 Abbé Nollet saw a translation of Franklin's paper describing his Philadelphia experiments. At first he could not believe that such a work had come out of America. He said that it must have been fabricated by his enemies in Paris to discredit him for the theory which he had developed regarding the nature of electricity. Afterwards, when he had been assured that there really existed such a person as Benjamin Franklin in Philadelphia, he wrote a long letter to Franklin defending his own theory and denying the validity of Franklin's experiments and the conclusions deduced from them.[17,18]

Franklin first was tempted to answer Nollet's attack, but instead he decided to let his papers shift for themselves believing it better to spend any time that he could spare from his public business on new experiments rather than in debate about those already made. He found that he was justified fully in this decision for, during the summer of 1752, other scientists throughout Europe repeated Franklin's experiments and proved the validity of his theories which then became accepted universally.[19] De le Monnier, in Paris, repeated his experiments with an iron rod connected to the earth through an iron wire. He found that it was not necessary to provide a sharp point on the rod and that it even might be placed horizontally. A man thus electrified could set fire to spirits of wine with his finger and repeat almost all of the useful experiments of artificial electricity.[20] LeRoy and Delibard showed the Philadelphia experiments before the king and court in Paris and all the curious in the city flocked to see them.[21]

Professor Ludolf and Mr. Mylius conducted the experiments in Berlin by using a pointed iron rod 12 feet long which was raised on a 50-foot pole and connected to a summer house through a long iron wire. When a thunderstorm approached great sparks appeared which sometimes could produce shocks through the body as violent as those obtained from Leyden jars.[22] Similar experiments also were made at Florence, Bologna, and other places on the continent of Europe.

In October 1752 Franklin wrote to his friend Peter Collinson as follows:

"As frequent mention is made in the public papers from Europe of the success of the Philadelphia experiment from drawing electric fire from the clouds by means of pointed rods of iron erected on high buildings, and so forth, it may be agreeable to the curious to be informed that the same experiment has succeeded in Philadelphia, though made in a different and more easy manner which anyone may try as follows: Make a small cross of two light strips of cedar; the arms so long as to reach to the four corners of a large thin silk handerchief when extended. Tie the corners of this to the extremities of the cross, so you have the body of the

kite; which being properly accommodated with a tail, loop, and string, will rise in the air like those made of paper; but this being a silk is fitter to bear wet and wind of a thunderstorm without tearing. To the top of the upright stick of the cross is to be fixed a very sharp pointed wire rising a foot or more above the wood. To the end of the twine next to the hand is to be tied a silk ribbon; and where the twine and silk join a key may be fastened.

"The kite is to be raised when a thunder gust appears to be coming on and the person who holds the string must stand within a door or window, or under some cover so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window.

"As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them and the kite, with all the twine will be electrified; and the loose filaments of the twine will stand out every way and be attracted by an approaching finger.

"When the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it will stream out plentifully from the key on the approach of your knuckle. At this key a phial may be charged; and from the electric fire thus obtained spirits may be kindled and all other electrical experiments be performed which are usually done by the help of a rubbed glass globe or tube and I think that the sameness of the electric matter and that of lightning has been completely demonstrated.

"I was pleased to hear of the success of my experiments in France, and that they have begun to erect points on their buildings. We have placed them on our academy and Statehouse spires."[23]

In view of the tremendous havoc wrought by lightning, it may seem surprising that only one case of serious accident to any of those engaged in these experiments has been recorded. George William Richman, professor of experimental philosophy and member of the Imperial Academy of Science in St. Petersburg, became interested in the study of lightning and repeated Franklin's Philadelphia experiment. He constructed a new form of electroscope which was provided with a graduated scale called a "demonstrator of electricity." He then erected several long iron bars on the roof of his house and connected these by chains to the electroscope in his laboratory. With this arrangement he had been observing the state of the atmosphere and also the magnitude of the charge he was able to obtain from his static generator. Upon the approach of a thunderstorm in the summer of 1753, he brought a friend to his laboratory to show him the way in which his instrument would indicate the presence of electricity during a storm. When they entered the room the electroscope registered 4 degrees, which the professor said meant that the storm was at a distance, but he said that if the indicator should rise to 45 degrees or more, it would represent a truly dangerous condition. As he stood near the instrument a stroke of lightning, which was said to be of unusual intensity, hit the circuit. Professor Richman was killed instantly, his friend was stunned, and much woodwork in the house in the path of the lightning was shattered as the stroke went to the ground.[24]

Possibly it was by mere good fortune that no direct lightning strokes occurred during any of the other experiments that have been mentioned. On the other hand, Franklin himself met with an accident while conducting quite a different kind of experiment which might have ended his career. He gave the following account:

"I have lately made an experiment in electricity that I desire never to repeat. Two nights ago, being about to kill a turkey by the shock from two glass jars, containing as much electrical fire as 40 common phials, I inadvertently took the whole through my arms and body, by receiving the fire from the united top wires with one hand while the other held a chain connecting with the outsides of both jars. The company present say, that the flash was very great and the crack as loud as a pistol; yet, my senses being instantly gone, I neither saw the one or heard the other; nor did I feel the stroke on my hand, though I afterwards found it raised a round swelling where the fire entered, as big as half a pistol-bullet; by which you may judge of the quickness of the electric fire, which by this instance seems to be greater than that of sound, light, or animal sensation. . . . . You may communicate this to Mr. Bowdoin, as a caution to him, but do not make it more public for I am ashamed to have been guilty of so notorious a blunder; a match for that of the Irishman, whom my sister told me of, who, to divert his wife poured the bottle of gunpowder on a live coal; or of that other, who, being about to steal powder, made a hole in the cask with a hot iron."[25]

Toward the close of the year 1752, after various reports had been received from many parts of Europe in confirmation of Franklin's theory of lightning, it was noted that no experiments of this character were being reported from England. William Watson offered the following explanation to the Royal Society:

"After the communications which we have received from several of our correspondents in different parts of the continent acquainting us with the success of their experiments last summer in endeavor to extract the electric power from the atmosphere during a thunderstorm in consequence of Mr. Franklin's hypothesis, it may be thought extraordinary that no accounts have been laid before you of our success here from the same experiments. That no want of attention therefore may be attributed to those here, who have been hitherto conversant in those inquiries, I thought proper to appraise you, that though several members of the Royal Society as well as myself, did upon the first advices from France prepare and set up the necessary apparatus for this purpose, we were defeated in our expectations from the uncommon coolness and dampness of the air here during the whole summer. We had only one thunderstorm in London and then the thunder was accompanied with rain, so that by wetting the apparatus the electricity was dissipated too soon to be perceived upon touching those parts of the apparatus which served to conduct it. This I say in general prevented us from verifying Mr. Franklin's hypothesis."[26]

Experiments with electric kites continued to be made well into the 19th century. In 1834 William Sturgeon, who was celebrated for his discovery of the electromagnet, thought that sufficient interest was being shown in this subject to make it desirable for him to write a paper cautioning the public against the improper use of the electric kite. The following extracts have been taken from this paper:

"Last Friday in the afternoon clouds began to form in various quarters of the heavens in rapid succession with every appearance of being highly electrical. I repaired to the Artillery grounds with

an electrical kite and in a short time got it afloat, letting out string through the hand from a coil that was thrown on the ground. When about 100 yards of the string had been let out, a tremendous discharge took place, which gave me such a blow in the chest and legs that I became completely stunned, let go the string and consequently the kite soon fell.

"The accident was owing entirely to my neglect and it could not possibly have happened had I taken the following precaution. Let all the string intended to be employed be first taken off the coil and stretched on the ground. Let now the insulating cord, glass or whatever is used for the purpose, be attached to the kite string and fastened to a peg in the ground. Next fasten the kite to the other end of the string and let it ascend from the hand.

"I find it convenient to have a sliding copper wire on the silken cord which can be moved by means of a long glass rod to any required distance from the main wired string, the other end being stuck in the ground. If the electric fire strikes two inches over the dry silken cord (and it will sometimes strike a yard), it would not be safe to approach it and no man could hold the string when it strikes over one inch.

"The only method of getting the kite down during a storm with safety is to unfasten the silken cord from its hold and let all go so that the kite falls."[27]

The afore-mentioned main wired string evidently means that a special kite string had been devised which utilized a fine wire central core to increase its conductivity.

William Sturgeon also gave a vivid account of the results that might be obtained through the ingenious experiment that had been devised by Franklin:

"On June 14th, at about eight o'clock in the evening, an electric storm passed over this place exhibiting lightning the most splendid ever beheld. The rain fell so heavily that it was with some difficulty that I got the kite afloat; and when up its greatest altitude, I imagine, did not exceed 50 yards. The silken cord also, which had been intended for the insulation, soon became so completely wet that it was no insulator at all. Notwithstanding all these impediments being in the way, I was much gratified with the display of the electric matter issuing from the end of the string to the wire, one end of which was laid on the ground, and the other attached to the silk at about four inches distance from the reel of the kite string. An uninterrupted play of fluid was seen over four inches of wet silken cord, not in sparks, but in a bundle of quivering purple ramifications, producing a noise similar to that produced by springing a watchman's rattle. Very long sparks, however, were frequently seen between the lower end of the wire (which rested on the grass) and the ground; several parts of the string towards the kite, where the wire was broken, were occasionally beautifully illuminated. The noise from the string in the air was like to the hissing of an immense flock of geese, with an occasional rattling or scraping sort of noise.

"Two noncommissioned officers of the Royal Artillery were standing by me the whole time and would gladly have approached close to the string had not I convinced them of the danger of touching or even coming near the string during the storm. We anxiously watched what was going on at the other end of the string and the display was beautiful beyond description. The reel was occasionally enveloped in a blaze of purple arborized electric fire, whose numberless branches ramified over the silken cord and through the air to the blades of grass which also became luminous on their points and edges, over a surface of some yards in circumference. We also saw a complete globe of fire pass over the silken cord which appeared to be about the size of a musket ball and which was exceedingly brilliant."[28]

The following account of electric kite experiments made by a local scientist in the north of England appeared in the *Lancaster Gazette* for April 5, 1834:

"On March 29th, I had a favorable opportunity of demonstrating experimentally to several of my friends at Kirkby Lonsdale, who had attended my recent course of lectures at that place, that an abundance of the electric fluid usually attends hail and snowstorms. During three hailstorms I floated one of my silken electric kites, with a wired string about 300 yards long, and insulated at its base in the usual way by means of a silken cord.

"The kite was elevated in each case about ten minutes prior to the arrival of the storm and the state of the atmosphere was ascertained and was found to be so feeble that not the slightest spark could be observed. As, however, the cloud from which hail was falling approached the kite, the fluid from the string presented itself in brilliant sparks to the knuckle; and during the transit of the cloud, became so abundantly discharged to the wire that was presented to the string that it struck in rapid succession through a stratum of six inches of air, and through three inches of air it presented a splendid continuous stream of electric fire.

"These appearances were exhibited in each experiment, but the display of the electric fire was the most magnificent in the second, which was during the fiercest hailstorm of that day. During an early part of this storm the electric fluid made a continuous rattling noise down the kite string (in consequence of the wire being broken in several places), and darted from the reel at the inferior extremity, to greater distances than in the other experiments. In one instance it struck over a stick about a yard long, to the hand of a young man who was presenting it to the kite string. Although the remote end of the stick was in contact with the ground by means of a very wet string and consequently a considerable discharge must have passed down the wet string to earth, yet the shock was so violent as to make the young man reel and nearly fall."[29]

As has been noted the first lightning rods were installed in 1752. One of the first installations in the United States was on the tower of the Statehouse, later known as Independence Hall, in Philadelphia. Franklin tried to stimulate the introduction of his method of lightning protection by citing cases of serious lightning damage to structures which might have been avoided by the use of lightning rods. In 1749 Captain John Waddell reported to the Royal Society that his ship *Dover*, newly launched, on a voyage from New York to London had encountered a very heavy storm in which electrical discharges resembling great torches appeared at the mastheads followed by a severe lightning stroke. Lightning shattered the main mast, disabled many of the crew, and caused so much damage to the body of the ship that it began to leak. The *Dover* had great difficulty in reaching land, accentuated by the fact that the four compasses of the ship were demagnetized.[30]

Franklin then sent a communication to the Royal Society showing how wire connections between the mastheads and the sea would have protected the ship and possibly would have prevented the stroke entirely. He also took that occasion to describe some interesting experiments that he had made in which he had magnetized steel needles by electrical means.[31]

Many reports of severe damage from lightning were

being discussed in the technical press of that day and Franklin contributed several of these. The following case was one of the most significant:

"Being in the town of Newbery in New England I was shown the effect of lightning on their church which had been struck a few months before.

"The steeple was a square tower of wood reaching 75 feet up from the ground to the place where the bell hung, over which rose a taper spire, of wood likewise, reaching 75 feet higher to the vane of weathercock. Near the bell was fixed an iron hammer to strike the hours; and from the tail of the hammer a wire went down through a small gimlet hole in the floor that the bell stood upon, and through a second floor in like manner; then horizontally under and near a plastered ceiling of that second floor, till it came near a plastered wall; then down by the side of that wall to a clock, which stood about 20 feet below the bell. The wire was not bigger than a common knitting needle.

"The spire was split all to pieces by lightning and the parts flung in all directions over the square in which the church stood, so that nothing remained above the bell. The lightning passed between the hammer and the clock on the above-mentioned wire without hurting either of the floors or having any effect upon them except making the gimlet holes a little bigger, and without hurting the plastered wall, or any part of the building so far as the aforesaid wire and pendulum wire of the clock extended; which latter wire was about the size of a goose quill. From the end of the pendulum down quite to the ground the building was exceeding rent and damaged and some of the stones in the foundation wall torn out and thrown to the distance of 20 or 30 feet. No part of the afore-mentioned long small wire between the clock and the hammer could be found except about two inches that hung to the tail of the hammer and about as much that was fastened to the clock; the rest being exploded and its particles dissipated in smoke and air as gunpowder is by common fire, and had only left a black smutty track on the plastering three or four inches broad, darkest in the middle and fainter towards the edges. All along the ceiling under which it passed and down the wall. These were effects and appearances on which I would only make a few remarks; namely:

1. That lightning in its passage through a building will leave wood to pass as far as it can in metal, and not enter the wood again till the conductor of metal ceases. And the same I have observed in other instances as to walls of brick and stone.

2. The quantity of lightning that passed through this steeple must have been very great by its effects on the lofty spire above the bell and on the square tower all below the end of the clock pendulum.

3. Great as the quantity was, it was conducted by a small wire and clock pendulum without the least damage to the building so far as they extended.

4. The pendulum rod being of sufficient thickness conducted the lightning without damage to itself; but the small wire was totally destroyed.

5. Though the small wire was itself destroyed yet it had conducted the lightning with safety to the building.

6. From the whole it seems probable that if even a small wire had been extended from the spindle of the vane to earth, before the storm, no damage would have been done to the steeple by that stroke of lightning though the wire itself had been destroyed."[2]

Franklin's activity in advising the adoption of his invention for the protection of property yielded rich results, and his lightning rods soon came into general use. In 1753 he received the Copley medal from the Royal Society of London for his scientific achievements and a little later was made an honorary member of the society by unanimous vote. At about the same time he also became a member of the Royal Academy of Science of Paris and within a few years was admitted to practically all of the learned societies of Europe. His Philadelphia friend, Ebenezer Kinnersley, who it will be recalled was started by Franklin on his scientific career, wrote a long letter to Franklin in 1763 which was read before the Royal Society and in which he described many of his experiments, closing with this eulogy:

"And now, Sir, I most heartily congratulate you on the pleasure you must have in finding your great and well-grounded expectations so far fulfilled. May this method of security from the destructive violence of one of the most awful powers of nature meet with such success, as to induce every good and grateful heart to bless God for this important discovery. May the benefit thereof be diffused over the whole globe. May it extend to the latest posterity of mankind; and make the name of Franklin, like that of Newton immortal."[33]

Franklin continued to correspond with his scientific friends regarding electrical matters, but from 1754, when he was appointed a delegate from Pennsylvania to the first General Assembly of all the Colonies, up until his death in 1790, he was unable to do any experimental work of his own as he was absorbed completely in his career as statesman, diplomat, and philanthropist.

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33. *Philosophical Transactions*, volume 53, page 97.

Turbine-Electric Coast Guard Cutters

WITH THE COMPLETION of its present construction program the United States Coast Guard will maintain a fleet of 13 turbine-electric a-c vessels having complete automatic control from the pilot house. They also are provided with either automatic or manual control from the engine room. Propulsion motors and generators are of minimum size because the use of regulated stability and automatic synchronizing permits the machines to be designed with very little inherent torque margin. Most of the vital propulsion auxiliaries are driven by motors taking power from a transformer connected to the propulsion bus and operate at from 90 to 15 cycles with facilities for transfer to a 60-cycle bus.

Each ship is equipped with one propulsion generator which supplies power to one synchronous propulsion motor. Speed control of the motor is obtained by adjusting the speed of the turbine driving the propulsion generator. The propulsion turbine is of the single-flow complete-expansion combined impulse and reaction type.

The accompanying figures illustrate equipment aboard the United States Coast Guard cutter *Mendota*.

Essential substance of an article by J. A. Wannlund, marine engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa.

Figure 1 (above). Auxiliary turbine generator sets

Figure 2 (below, left). Propulsion control and auxiliary switchboards

Figure 3 (below). Propulsion turbine generator set

Electric Measuring Instruments

D. M. NIELSEN

During recent years the influence of electronics on process measurement and control instruments has been evidenced by a great increase in electric measuring instruments. The author of this article analyzes the characteristics of these new instruments in general and, by way of illustration, describes several specific products and their operation. Comparisons of electronic instruments with the corresponding mechanical types indicate the prospective applications for each.

THE PURPOSE of this article is to present a brief survey of new electric instruments for measuring process variables such as temperature, pressure, flow, and hydrogen-ion concentration. In this respect it has three major aims:

1. To cover recent developments by the process instrument companies in electrical types of recording and controlling instruments, with emphasis on new electronic instruments.
2. To point out the way in which the application fields of electric equipment companies and the process instrument companies are beginning to overlap.
3. To point out the impact of electronics on process measurement and control instruments.

One possible approach to this general subject of new developments and trends in instruments is to consider separately the various functional elements in recording and controlling instruments, especially the use of electronic techniques in each.

Functionally, an instrument may be broken down conveniently into the various units shown in Figure 1.

Electronic units possibly could be used as sensitive elements, as part or all of a recording mechanism, as a controller mechanism, and as a final control element. Instruments or control equipment using electronic tubes and circuits in each of these functional ways are on the market.

However, before investigating these various uses of electronics some background information on the characteristics of vacuum tubes as used in instruments is desirable.

CHARACTERISTICS OF VACUUM TUBES FOR INSTRUMENT USE

Vacuum tubes commonly are employed in rectifiers, control switches, amplifiers, and oscillators but in industrial equipment there is strong competition from other electric devices which already have been in use commercially and which have given satisfactory operation. Copper oxide and selenium oxide rectifiers, for example, have been utilized widely in instruments for many applications. The number and types of mechanical relays and switches available today are extremely great. Recording and indicating null-balance electric instruments for some years have used electromechanical amplifiers in galvanometer and chopper-type balancing systems. In laboratory bridges, the use of tuning fork audio-frequency generators long has been common.

Some of the characteristics of vacuum tubes which are especially useful in instrument applications are the following:

1. High input impedance.
2. High amplification.
3. Sturdiness and comparative immunity to vibration.
4. High speed action.
5. Mechanical simplicity.
6. Absence of moving parts.
7. Versatility.
8. Low cost.
9. Inherent load-limiting characteristics.

Other characteristics of vacuum tubes limit their use in instruments. These characteristics include:

1. Variation in tube characteristics.
2. Nonlinearity of tube parameters.
3. Effect of changes of A, B, and C battery voltages and grid and plate circuit elements on tube characteristics.
4. Change in filament emission characteristics with age and service life.
5. Low power efficiency.
6. Ambient temperature effects.
7. Limited tube life.

The following discussion considers the characteristics of vacuum tubes, especially as they apply to use in the various functional parts of instrument systems (sensitive elements, measuring mechanisms, controlling mechanisms, and so forth).

SENSITIVE ELEMENTS FOR ELECTRIC INSTRUMENTS

Electric sensitive elements are conversion units in which a change of a physical variable, for example, temperature, radiant energy, pressure, flow, pH, solution conductivity, strain, or gas composition produces a change of some electrical variable such as voltage, current, resistance, capacitance, or inductance.

The outputs of the various types of sensitive elements for process application are often at very low levels and

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they have other characteristics which make instrumentation difficult.

Table I lists some of the generally used electric sensitive elements for process measurements, classified by the physical variable measured, and includes typical output level and element impedance data.

Table II gives additional applications of the same elements in process applications where the basic sensitive element is combined with another responsive element. This may be illustrated by the combination of a strain gauge with an elastic tube for fluid pressure measurement. These two tables include almost every variable encountered in process work.

Of all the electric sensitive elements listed in these tables only three are electronic in nature. Very probably this is to be expected from the very purpose of a sensitive element. Considering that the action of electronic tubes is based on controlling the flow of streams of electrons or ions between electrodes in an evacuated or a gas-filled enclosure, the problem of designing electronic sensitive elements then becomes one of influencing this electron or ion current by means of the variable which is to be measured.

Little has been done so far on commercial development of such units except for a few specialized electronic sensitive elements for process measurements briefly described later. It is pertinent at this point to discuss several widely used electric sensitive elements to see how instrument design has been influenced by either their conversion characteristics or by other problems accompanying their use.

Briefly, and inaccurately, the glass electrode is a sensitive element which produces a direct voltage proportional to the pH (or hydrogen ion concentration) of an aqueous solution in which it is immersed.

The direct-potential difference produced may be as great as about 0.8 volt so it would seem simple to measure until it is considered that the glass membrane of the electrode is by general engineering standards an excellent insulator and that the ion current through the glass, which causes the output voltage, is extremely small. If the measuring circuit draws off electrons faster than the flow of ions through the glass can restore them, the potential difference balance is upset and measuring errors result. The internal resistance of various types of glass electrodes is from 6 to 500 megohms and commonly is greater than 50 megohms. For a typical electrode the current from the electrode during continuous measurement must not exceed 10^{-11} amperes.

This characteristic limits greatly the types of measuring equipment which can be used with glass electrodes. The instruments now used are electronic types, usually d-c amplifiers. The output circuits of these amplifiers supply enough power to operate a moving-coil d-c milliammeter or else a potentiometer recorder.

Wire resistance strain gauges are primary elements for measuring small linear changes of dimension of the surfaces to which they are attached. Surface strain causes a proportional percentage change of electrical resistance of the gauge, which is measured with a suitable instrument.

The major problem in strain gauge instrument design is that of measuring accurately the very small changes in gauge resistance resulting from applied strain. For example, it is desired to record accurately strains causing a resistance change of 0.0024 ohm in a gauge having a resistance of approximately 120 ohms.

A second major problem is the development of suitable null-balance indicators for manually operated bridges and automatic balancing mechanisms for recorders. For the measuring accuracy required, the instrument balancing system must take positive action on unbalance voltages of less than 15 microvolts.

Table I. Electric Sensitive Elements for Process Applications

Physical Variable	Sensitive Element: Type	Sensitive Element: Electrical Variable	Measuring Circuit	Typical Operating Conditions: Instrument Range	Typical Operating Conditions: Output Range*	Element Impedance (Ohms)**
Temperature	Thermocouple	D-c electromotive force	Potentiometer	0–1,200 degrees Fahrenheit	0–32 millivolt	10–50
	Resistance bulb	Resistance change	Bridge	0–100 degrees Fahrenheit	0–5 per cent unbalance	25–200
Radiant energy	Vacuum thermocouple	D-c electromotive force	Potentiometer		0–1 millivolt	<100
	Bolometer	Resistance change	Bridge		0–1 per cent unbalance	35
	Photoelectric cell (Cs+Ag)	Electron current	Potentiometer			$>10^5$
Strain	Thermopile	D-c electromotive force			0–3 millivolt	25–100
	Wire gauge	Resistance change	Bridge	0.001 inch per inch	0–0.2 per cent unbalance	120–150
	Inductive gauge	Inductance change	Bridge	0.001inch per inch	0–20 per cent unbalance	<100
	Capacity gauge	Capacitance change	Bridge or special	0.001 inch per inch	0–20 per cent unbalance	$>10^5$
	Piezo crystal	D-c electromotive force	Potentiometer or oscilloscope	0.001 inch per inch	0–1.0 volt	
Pressure	Pirani gauge	Resistance change	Bridge	0.1–10 microns		100
	Ionization gauge	Direct current	Special vacuum tube	10^{-4}–10^{-9} millimeters Hg		5,000
Miscellaneous						
pH	Glass electrode	D-c electromotive force	Potentiometer	0–7.0 pH	0–0.4 volt	$(6–500)\times10^6$
Solution strength	Conductivity cell	Resistance change	Bridge	0–30 micromhos	0–1,300 per cent	3,300–50,000
Gas analysis	Thermal conductivity cell	Resistance change	Bridge	0–20 per cent CO_2	0–0.2 per cent unbalance	50
Polarography	Dropping Hg electrode	D-c electromotive force			0–3 volt	

* Bridge circuits assume that all arms equal resistance when sensitive element resistance at lowest value. ** Including leads.

Table II. Applications of Sensitive Elements Combined With Other Responsive Elements

Primary Variable Measured	Secondary Variable	Means of Measurement
Temperature difference	Humidity (relative)	Wet and dry bulb
Temperature	Humidity (absolute)	Hygroscopic equilibrium element
Radiant energy	Mass spectrometer	
	Absorption spectrometer	
Strain	Fluid pressure	
	Fluid pressure difference	
	Fluid flow rate	
	Fluid liquid level	
	Weight	
	Dimension gauging	
	Force	
	Torque	
Radiation	Colorimetric analysis	
	Turbidity	
Capacitance	Moisture	Hygroscopic dielectric in moisture balance with unknown material
	Thickness	Nonhygroscopic material as dielectric
Inductance	Thickness	Magnetic materials
Resistance	Moisture Thickness	Hygroscopic material

The answer to these problems was the design of instruments using electronic balancing units.

Thermocouples are too well known as sensitive elements for the measurement of temperature to need description.

Today there is a strong trend toward the general use of electronic self-balancing recording potentiometers because of the various industrial application problems plus the limitations of mechanical instruments rather than by the electrical characteristics of thermocouples.

Factors contributing to this trend include the following:

1. Modern continuous unit processes, notably in the chemical and petroleum refining industries, have required narrower measuring ranges to obtain greater sensitivity and better automatic control.

2. Rebalancing speed of mechanical recorders necessarily is slow because of the response characteristics of the galvanometer and the intermittent balancing cycle.

3. The general tendency of galvanometers toward unstable and erratic action under severe vibration conditions is a handicap.

4. Mechanical balancing systems, though highly perfected, do require periodic maintenance and skilled adjustment to operate properly, as in the case of any fine machine.

ELECTRONIC SENSITIVE ELEMENTS

Electronic sensitive elements may be divided into two general classes: photoelectric cells in which the electron stream is varied by radiant energy passing through the transparent wall and gas pressure or analysis tubes which depend on passing a continuous sample of gas vapor through the tube and which measure resulting variations in ion current.

Photoelectric cells are special vacuum tubes used as sensitive elements with electric instruments for the detection or measurement of radiant energy. They are used primarily in electric optical instruments such as spectrophotometers, color comparators, and photometers.

The ionization gauge measures very low absolute pressures over the range of 0.1–200 microns. It uses a special three-element (filament, grid, and plate) vacuum tube whose envelope is connected to the vacuum system so that the system pressure exists in the tube. The gas in the tube is ionized by collision and the ion current to the plate is proportional to the number of gas molecules present, or to the gas pressure in the tube. The plate current meter is calibrated in terms of gas pressure in microns.

The mass spectrometer analyzes a stream of gas by separating it into beams of molecules according to mass while recording the presence and relative percentage of each beam.

The heart of this instrument is a special electronic analysis tube. The gas stream is introduced into the tube at a constant rate and passes through a high velocity electron beam which ionizes gas molecules by collision. The stream of gas ions is formed into a beam by suitable electrostatic focusing and accelerating electrodes. The path of these ions then is bent by a magnetic field and the ions pass into a curved part of the tube at the end of which is a collecting electrode. If the magnetic field is weak, only the ions with small mass will be deflected sufficiently to hit the collecting electrode. If the magnetic field is increased gradually, ions with successively greater mass will hit the collecting electrode. The ion current at the collecting electrode and through the external circuit will be proportional to the number of the ions of one particular mass striking the electrode at the time. Thus, if the relation between the strength of the magnetic field and the mass of the ions which will strike the electrode is known, then a curve of the collecting electrode current against the ion mass can be plotted to show the percentage composition of the original gas sample classified by mass of the molecules present.

ELECTRONIC MEASURING INSTRUMENTS

Electronic process instruments measure the output of electric sensitive elements. That is, they measure one of the electrical variables; voltage, current, resistance, inductance, or capacitance.

For purposes of analysis, null-balance measuring instruments can be considered as made up of various functional units:

1. Measuring circuit, where the magnitude of an unknown variable is measured by comparison with an adjustable standard.

2. Null-balance electromechanical or electronic unit which detects unbalance between magnitudes of unknown and adjustable standard, amplifies this difference, and through a power motor readjusts standard to obtain an exact balance in the measuring circuit, and simultaneously drives the indicating or recording mechanism.

3. Indicating or recording mechanism, a pointer and scale or pen and chart which converts position of slide wire contact or

other type of adjustable standard into a direct reading of the unknown variable.

The measuring circuits in electronic instruments are the same type as those used in mechanical instruments and in laboratory equipment. Potentiometers measure voltage and current. Bridges are used to measure resistance, inductance, and capacitance.

The elements in these circuits are fixed and adjustable resistors, capacitors, or inductors which are highly stable under varying conditions of temperature and humidity and also age. In comparison, the resistance and capacitance properties of vacuum tubes are affected greatly by such conditions of operation as grid filament and plate voltages, ambient temperatures, service history of tube, and so forth. The various operating characteristics of vacuum tubes are so interrelated and so limited in value practically by construction requirements and other factors that the design of commercial tubes to produce desired values of resistance or capacitance over the range of values necessary for measuring circuit use is now impractical.

On adjustable standards much the same comparison as for fixed elements holds. In addition, there is the vital difference for instrument use that the end product of the instrument is the motion of an indicating pointer or a recording pen which usually is connected mechanically to a slide wire contact or a capacitor rotor. Someplace in the instrument there must be this electromechanical link. The vacuum tube is not designed as yet for this type of application and so, altogether, it now has no place in instrument measuring circuits as a resistance, capacitance, or inductance element. On the other hand, vacuum tubes have been used very successfully in oscillator circuits for a-c power supplies for bridges.

Vacuum tubes also have been used widely in balance indicators in manually operated instruments and in automatic balancing systems for recorders. In these applications they perform a power relay or a servomechanism function. That is, they replace a galvanometer balance detector and an intermittently operating clutch and feeler slide wire contact drive mechanism. In practically every case, the number of moving parts in the instrument is reduced greatly and, as the tubes are not in the measuring circuit, their performance variations affect balancing speed and limiting sensitivity primarily and measuring accuracy only to a minor extent. And it is simple to design with ample safety factors for these effects.

To point out briefly various features of the electronic servomechanisms now being used in automatic balancing systems, various commercial recording instruments on the market at present will be described. *

* No mention is made of the instruments built by Bailey Meter Company because no published information was available at the time this article was prepared. These instruments have been described in detail in a paper presented before the Industrial Instruments and Regulators Division of American Society of Mechanical Engineers at the 1944 Annual Meeting.

The "Brown Electronik D-C Potentiometer Recorder" is shown in Figure 2. A conventional slide wire potentiometer circuit is used in this instrument. The slide wire contact is connected mechanically to the recording pen and pointer and the balancing drive motor through a cable system and gears.

The d-c unbalance voltage from the potentiometer is converted into an alternating voltage before amplifying. The d-c–a-c conversion unit includes a synchronous vibrator switch and a coupling transformer. The vibrator is a magnetically polarized metal reed which is fixed at one end while the other end is free to vibrate. A solenoid coil is mounted near the free end of the reed. This coil, which is energized from the a-c power supply source, alternately attracts and repels the polarized metal reed at power frequency. The reed carries moving contacts and oscillates back and forth between two fixed contacts. The vibrator thus acts as a single-pole double-throw switch. As shown in the wiring diagram, it is connected into the unbalance circuit in series with the coupling transformer so that it reverses connections from the unbalance circuit to the primary winding of the coupling transformer 60 times a second (or whatever the line frequency is) and so reverses the direction of flow of the d-c unbalance current in the transformer primary winding.

This reversing direct current in the primary winding induces in the transformer secondary winding an alternating voltage which is approximately proportional to the unbalance voltage. The alternating voltage also reverses in phase as the slide wire contact passes through null balance point. This voltage is amplified by a conventional three-stage a-c amplifier to control the balancing drive motor, a two-phase a-c induction motor. The operation of this depends on the production of a rotating magnetic field by having the alternating currents in the two windings 90 degrees out of phase. If the "control" winding current leads the "power" winding current by 90 degrees, the motor runs one way. If the "control" winding current lags the "power" winding current by 90 degrees the motor runs the other way.

The current through the "control" winding is controlled by two power amplifier tubes connected so that

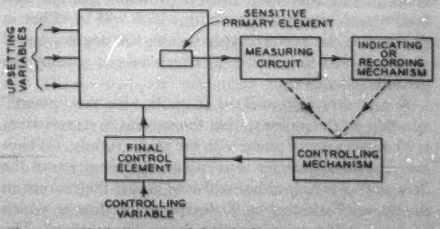

Figure 1. Block diagram of electrical process measurement and control system

the plate currents of both tubes flow through the winding. The amplified a-c unbalance voltage is applied to the grids of both these tubes and controls the amount of plate current flowing. The plate circuits of these tubes are supplied separately with alternating voltages by two power transformer windings connected so that one plate is positive when the other is negative. As these tubes pass plate current only when their plates are at positive potentials, and this condition occurs alternately in the two tubes, only one tube can pass current at any one time.

If the potentiometer circuit is unbalanced, the amplified a-c unbalance voltage is applied to the grids of both power amplifier tubes. As this same voltage is applied

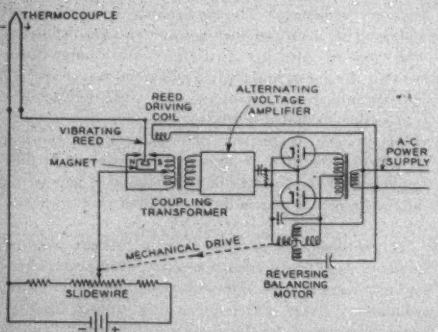

Figure 2. Brown "Electronik" self-balancing potentiometer

to the grids of both tubes and the plates of these tubes are supplied with oppositely phased alternating current, this unbalance voltage will be in phase with the plate voltage on one tube and 180 degrees out of phase with the plate voltage on the other tube. In the tube in which grid and plate voltages are in phase (that is, both are positive at the same time), the plate current will increase and in the other tube (in which the grid is negative when the plate is positive), the plate current will decrease. The resultant "control" winding current thus becomes an alternating current, which will be either in phase with the power supply or else 180 degrees out of phase with it, depending on which tube is passing the greater current.

A capacitor is connected in series with the "power" winding on the motor so that the current in this winding is 90 degrees out of phase with the power supply. Whenever the potentiometer is unbalanced, the current in the "control" winding either will lead or lag the current in the "power" winding by 90 degrees, depending on which power amplifier tube is passing the greater current. The control as to which tube passes the greater current thus depends on the phase of the amplified a-c unbalance voltage, which in turn is determined by whether the potentiometer slide wire contact is above or below balance. In this way the balancing motor rotates in the proper direction to drive the slide contact back to the balance point and to drive the recording pen and indicating pointer.

The magnitude of the alternating current in the control winding is approximately proportional to the d-c potentiometer unbalance voltage. This in itself means fairly good balancing action because the motor power and speed decrease as the slide wire contact approaches the balance point. It also means that the motor has low torque for small unbalance conditions, which is undesirable. This difficulty is avoided practically by using high amplification of the unbalance voltage so that the motor develops a high torque on small changes.

The "control" winding has a pulsating direct current flowing through it at the balance point. The capacitor connected across this winding smooths out the pulsating current to give a steady direct current which, flowing through the control winding, applies a braking effect to the motor.

Figure 3 illustrates a Leeds and Northrup "Speedomax Electronic D-C Potentiometer Recorder" in which a conventional slide wire potentiometer circuit is used. The slide wire contact carries a recording pen carriage and is connected mechanically to the balancing drive motor through a cable system.

The d-c unbalance voltage from the potentiometer is converted into an alternating voltage before amplifying. The actual d-c–a-c conversion is made by a modulator and a coupling transformer. This modulator and the primary winding of the coupling transformer are connected in series in the unbalance circuit where a galvanometer would be situated in mechanical instruments. The modulator is a carbon microphone button driven magnetically by an exciting coil which is energized from the a-c power supply of the instrument. As the button diaphragm vibrates back and forth at power-line frequency, it changes the pressure on the carbon particles in the button which, in turn, changes the electrical resistance of the button. The variation of resistance in the modulator causes the d-c unbalance current flowing through this circuit to pulsate. The pulsating part of this direct current is in effect an alternating voltage that induces an alternating voltage at power supply frequency in the secondary winding which is connected to the input of a conventional vacuum tube amplifier. This voltage is approximately proportional in amplitude to the d-c unbalance voltage and reverses in phase as the potentiometer slide wire contact passes through the null balance point.

The balancing drive motor is a series d-c motor whose reversing action is provided by two separate field windings which are connected in the plate circuits of two thyratron tubes. These tubes are gas-filled triodes which act

as grid controlled rectifiers to supply pulsating direct current to the motor fields.

The amplified a-c unbalance voltage is applied to the two thyratron tube grids through a transformer so that equal but opposite sign voltages are impressed on them. That is, one grid is negative when the other is positive and conversely the thyratron plate voltages are alternating current supplied by a transformer connected so that both plate circuits are positive at the same time. Because of this method of connection of grids and plates of the thyratrons, in one tube the grid voltage will be positive at the same time that the plate voltage is positive and this tube will pass direct current through its motor field winding. In the other tube, the grid will be negative when the plate is positive and a small or even zero current will flow in its motor winding.

The wiring connections are such that the amplified a-c unbalance voltages fire the proper thyratron to energize the correct series field winding in order for the motor to drive the slide wire contact back to balance. As previously mentioned, the a-c unbalance voltage reverses phase when the potentiometer goes through the balance point, the opposite thyratron then fires, and the slide wire contact is driven in the other direction.

The method used to prevent hunting is the connection of a d-c tachometer generator (mechanically driven by the balancing motor) in series with the modulator and coupling transformer in the potentiometer unbalance circuit. This generates a direct voltage with polarity determined by its direction of rotation and voltage magnitude determined by speed of rotation. This generator is connected so that its voltage bucks any potentiometer unbalance voltage.

With the balancing motor driving at a constant speed back to the potentiometer balance point, the tachometer voltage is constant and the unbalance voltage is decreasing. As soon as the tachometer voltage becomes greater than the unbalance voltage, the net voltage in the unbalance circuit reverses polarity. The resulting a-c unbalance voltage reverses phase and braking torque is applied to the balancing motor, which continues to rotate in the same direction but at a decreasing speed. As it slows down, the tachometer generator voltage falls. With both the tachometer and the unbalance voltages falling together, the instrument comes to balance smoothly and without overshoot.

In the Tagliabue "Celectray D-C Potentiometer Recorder" shown in Figure 4 a conventional slide wire potentiometer circuit is used. The slide wire contact carries a recording pen carriage, and is connected mechanically to the balancing drive motor. Potentiometer unbalance is detected and amplified by a combination of a mirror galvanometer, photoelectric cell, and an amplifier tube.

The galvanometer is connected in a conventional way in the slide wire contact circuit so that its coil will deflect in proportion to the amount of potentiometer unbalance and in a direction determined by whether the potentiometer slide wire contact is above or below the balance point. A light beam from a lamp source is reflected by the galvanometer mirror back past a controlling edge onto the sensitive surface of a photoelectric cell. The instrument optical system is adjusted so that the beam is cut off partly by the controlling edge when the potentiometer is balanced. If the slide wire contact is below the balance point, the galvanometer deflects so that all the light is cut off from the cell. If the contact is above the balance point, then the full light beam strikes the cell.

The photoelectric cell is connected between the grid

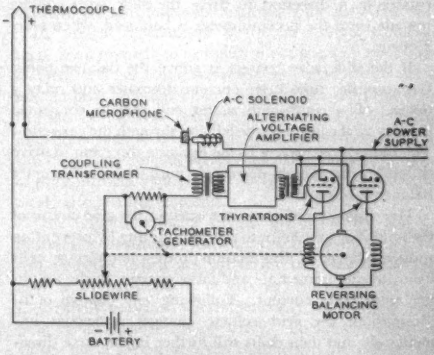

Figure 3. Leeds and Northrup Speedomax electronic self-balancing potentiometer

and plate of the amplifier tube and in series with a resistor between the grid and the filament. This circuit is a voltage divider in which the resistance of the photoelectric cell is decreased when light falls on it. The voltage on the grid of the tube thus is determined by the amount of illumination on the photoelectric cell.

When the galvanometer deflects to increase the illumination on the photoelectric cell, more current will flow through it driving the grid of the vacuum tube more positive so that its plate current will increase. Conversely, when the galvanometer deflects in the opposite direction to decrease the illumination on the photoelectric cell, the amplifier tube plate current will decrease. These variations in amplifier tube plate current control the balancing drive motor through a pair of telephone-type relays.

The balancing drive motor is a split-phase induction motor with two similar windings, one of which is connected directly to the power supply while the other is connected through a capacitor. This makes the current in the two windings 90 degrees out of phase and the motor

operates as a two-phase induction motor. The direction of the rotation of the motor is reversed by shifting the phasing capacitor from one winding to the other.

The wiring diagram in Figure 4 shows the control relays and their connections to the balancing drive motor. Relay 1 will close on a slightly lower current than relay 2.

The instrument is adjusted so that when the potentiometer is balanced relay 1 is closed and relay 2 is open. In this condition, the motor control contacts on both relays are open and the motor stands still.

The amplifier tube plate current increases when the slide wire contact is below the null-balance point which closes relay 2. This connects the left-hand motor winding directly to the line and the right-hand winding to the line through the capacitor. The balancing motor then rotates in a direction to drive the slide wire contact upscale until the potentiometer is balanced, when relay 2 opens.

If the slide wire contact is above the balance point, the amplifier tube plate current decreases and relay 1 opens. The right-hand motor coil now is connected directly to the line and the left coil through the capacitor. The motor now rotates in the opposite direction to drive the slide wire contact downscale until the potentiometer balance is restored.

The capacity-resistance net work in the grid circuit of the amplifier tube helps to prevent hunting by preventing sudden changes of illumination on the photoelectric cells from causing immediate and large changes in the amplifier tube plate current. Following any change of illumination, the grid voltage changes somewhat immediately and then drifts still further in the same direction until the final full change produced by the change of illumination on the photoelectric cell is reached.

A second antihunting means is the pair of "advancing electromotive force" contacts on the relays. When the slide wire contact is below the null-balance point, relay 2 is closed as described. The close of the "advancing electromotive force" contact on relay 2 lowers the potential of the reference point. The introduction of this extra voltage causes the galvanometer to reach the balance point and open relay 2 before the potentiometer circuit has reached the null position. The motor continues to coast after relay 2 opens, driving the contact towards true balance but there may be several short intermittent relay operations with resulting small boosting or braking actions before the contact does reach balance.

When the slide wire contact is above the null-balance point, the opening of relay 1 raises the potential at the reference point so the galvanometer again reaches the null position before the potentiometer is balanced fully and the final balance point is reached with small stepping actions.

A Foxboro "Dynalog A-C Bridge Recorder" is illustrated in Figures 5 and 6 in which a modified Wheatstone bridge circuit is used. This bridge is energized with 1,000 cycles per second alternating current generated by a vacuum tube oscillator of conventional design. A novel feature of this circuit is the use of a variable air capacitor instead of a slide wire for the balancing arm of the bridge.

The a-c unbalance voltage from the bridge is impressed directly on the control grid of the first tube of a three-stage amplifier of conventional design. The amplified voltage from the output of the third stage is approximately proportional to the magnitude of bridge unbalance up to the point where the amplifier overloads and it reverses phase as the rotor of balancing capacitor passes through the bridge balance point.

The amplified unbalance voltage is impressed on both grids of a twin triode tube, which functions as a phase discriminator. The plate voltages for the two triode units of this tube are 1,000 cycles per second alternating current supplied from the same oscillator which feeds the measuring bridge circuit. These two plate voltages are 180 degrees out of phase, thus any unbalance voltage applied to the grids will be in phase with one plate voltage and 180 degrees out of phase with the other one. In the triode unit in which the grid and plate voltages are in phase, a large pulsating rectified a-c plate current will flow and a large voltage will appear across the plate load resistor. In the other triode unit, the grid will be negative when the plate is positive and the plate current and output voltage will be small or even may fall to zero. By the use of large capacities shunted around the plate load resistors, the output voltages are made substantially direct current.

With a suitable network, the algebraic difference between these two output voltages is split equally and applied as two equal but opposite in sign d-c bias voltages to the grids of a twin-triode power amplifier tube. Connected in the plate circuits of these two triode units are

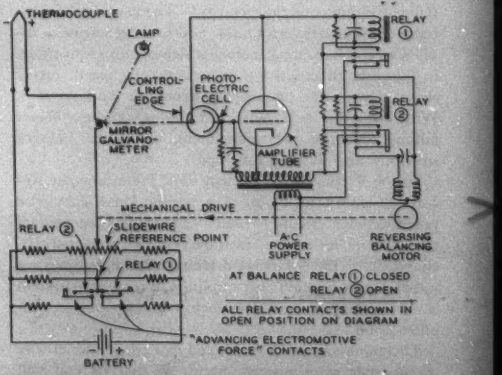

Figure 4. Tagliabue Celectray self-balancing potentiometer

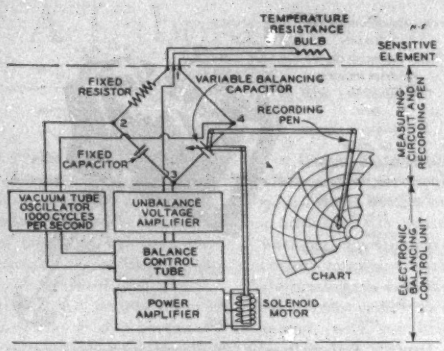

Figure 5. Foxboro Dynalog self-balancing bridge

the two coils of a reciprocating magnetic motor. This motor consists of a pair of solenoid coils surrounding a cylindrical iron core which is connected by a rigid drive link to the balancing capacitor rotor. Because of suitable design, the magnetic force exerted by the coils on the moving core is practically independent of core position and is proportional only to the square of the currents in the two coils.

At bridge balance (when there is zero input alternating voltage to the discriminator tube), equal direct currents flow in the two motor coils and the balancing capacitor is held at the correct position through a force balance in the magnetic motor. Any bridge unbalance voltage is amplified and unbalances the two motor coil currents to drive the core and balancing capacitor rotor to the correct new balance position.

The distinctive feature of this instrument is in the mechanical design of the balancing system to obtain simplicity and to eliminate certain maintenance problems rather than in the electronic circuit used. Figure 6 shows the balancing capacitor magnetic drive motor and the recording pen movement, with the two links connecting these units.

BROAD TRENDS

In summary, some personal opinions are offered on current trends in process instrumentation, especially in relation to the various new types of electronic instruments mentioned.

There is a general increase in the proportion of electric process instruments being used and there is every reason to expect that this trend will be accelerated by the development of electronic instruments. Some of the factors responsible for this swing are the following:

1. More accurate measurement.
2. More sensitive measurement.
3. High recording speed.
4. Measurement of variables impossible with mechanical instruments.
5. Separate sensitive elements and instruments and low priced, easy, and quick replacement of sensitive elements without removing instrument.
6. Elimination of capillary tubing and static pressure lines.
7. Instantaneous transmission of measurements.
8. Multiple measurements with a single instrument and a selector switch.
9. Addition, subtraction, or ratio computations with special measuring circuits.

Beyond these factors, all of which now are realizable, is the hope of getting a truly universal instrument which would measure all process variables by changing the sensitive element and some measuring circuit elements.

In control mechanisms and final control elements there is no immediate prospect of electrical or electronic techniques superseding the pneumatic equipment which now largely dominates the process field. Electric control mechanism now predominate only in a few specialized fields such as heat-treating and where electric control does have obvious advantages because of the nature of the controlled equipment, for instance, motor starters or electric heating elements.

One important factor in this picture is the relative availability of suitable pneumatic and electric final control elements which are valves for the control of fluid flow in a great majority of process control applications. Electrically operated valves generally use either a solenoid or an electric motor drive. Pneumatic types of valves use a spring opposed diaphragm air motor. In general, the pneumatic types are less expensive, more simple and sturdy, and require less maintenance. In addition, they are not an explosion hazard and do take a positive position in case of air failure.

Another factor is the relative performance of electric and pneumatic control mechanisms in proportional or proportional plus reset control action types. In the present situation better results can be obtained with pneumatic mechanisms on most process applications. It is a rather difficult problem to obtain with electrical networks the slow reset action needed for many processes.

Much work has been done during the war on electric and electronic servomechanisms for use in fire control, stabilizing mechanisms, for guns, bombsights and other mechanisms, radar equipment, and airplane flight control. It well may be that out of these developments will come suitable low-priced electric valve operators, while other approaches to the controller problem, as the use of pneumatic-electric or mechanical-electric reset mechanisms, may give satisfactory results.

The field of direct operated process electric control equipment is relatively undeveloped. In the mechanical equipment field, there are available low priced self-operated pressure and temperature regulators which use power supplied from the controlled medium. Practically

all electric control mechanisms operate from the movement or the position of a pointer or recording pen on a mechanical or electric measuring instrument. However, there are already signs that all-electric control equipment, in which the measuring circuit and the controlling circuit are combined in a single unit to give an instrument with a calibrated setting mechanism but without indication or record of the controlled variable, will be placed on the market during the postwar period.

There is a growing tendency for the fields covered by the process instrument companies and by electric equipment manufacturers to meet and overlap.

On one hand, the process instrument companies are getting into the measurement of what might be called "mechanical" variables and the control of prime movers or power transmission equipment instead of merely valves. Typical examples are: automatic operation and safety control or motor driven pumping equipment; torque measurement on centrifugal filters, agitators in reaction vessels, pulp washers, and so forth; load and mechanical pressure control on pulp beaters, calendars, squeeze rolls, and so forth; tension control on paper, cloth, cellophane, or rubber sheets in process.

On the other hand, the electric equipment companies are developing new control mechanisms which are highly useful with suitable measuring instruments. Examples are the many types of electronic motor speed control equipment. Also useful are many electronic relays, timers, and standard photoelectric cell pickup and control units.

It is evident that this development of a common field of work makes important the use of a common terminology for automatic control equipment. The terminology used by electrical engineers apparently has been taken over intact from the field of turbine speed governing. That used in process control has been far more casual in growth and has been semicodified only during the past several years by the instrument group in The American Society of Mechanical Engineers.

There still is a decided conflict between these two accepted sets of control terminology. Examples are the different usage of such words as "control" and "regulation." Another example is the use of two different words for the same meaning, as in the case of control point "droop" and "drift."

The use of two different sets of terminology to describe the same behavior of control equipment only confuses the users and purchasers of this equipment. It also makes the growth of a common understanding between electrical and mechanical engineers more difficult. Also, the use of a common terminology does have a special importance at this time because of the increasing use of both electrical and hydraulic analogues to interpret and predict the transient behavior of both chemical processes and mechanical equipment under automatic control.

One final opinion might be ventured as to the extent

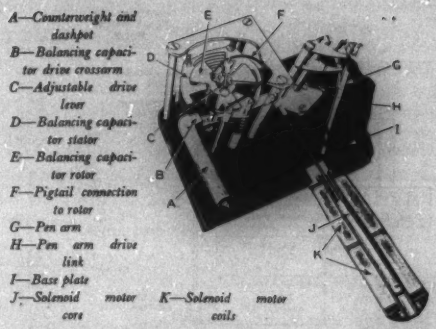

Figure 6. Foxboro Dynalog self-balancing a-c bridge construction of balancing capacitor, drive motor, and recording pen

to which electronic instruments will replace mechanical types. In this period following the war, there undoubtedly will be a considerable number of new types of electronic measuring and controlling instruments placed on the market. Many of these will be marketed by companies building standardized units for sale in package form but equipment selling of this type also means very little application engineering by the maker. As a result, this class of equipment may do more harm than good to the general use of electronics in industry until users develop their own "know-how" on electronics.

If history is any teacher, there will be a temporary swing to the use of these instruments because of advantages of mechanical simplicity and better control action. However, looking at the examples of motor speed control and electric welding control, this swing will stimulate the development of other mechano-electric and pneumatic mechanisms to the point where competition between these types will be based on economic factors. It is possible that the majority of the dollar volume of instrument business in this way will be reduced to package sales. Certainly the development of a universal electronic instrument, as mentioned previously, which could be produced in quantity, would have a strong influence in this direction.

There is a large segment of the process instrument market which does not appear likely to fall into this classification. This is the petroleum refining and the chemical market. In these fields an intangible and extremely important part of the sale price of instrument equipment has been the engineering of automatic control, including advice on desirable changes in process equipment to make better control possible. It almost can be said that the difference in relative success between the various instrument companies has been in the quality of the engineering service which they supplied to their customers.

A Laboratory for Basic Electronics

P. M. HONNELL W. E. STROHM

The United States Military Academy now has a 140-position electronics laboratory in which future Army officers are given instruction in a field that has greatly influenced modern warfare. Provision is made for supply from central sources, to each student position, of alternating and direct voltages, including radio frequencies up to 18 megacycles per second, with suitable protective measures.

THE MECHANIZATION of modern warfare has affected all echelons of the Army, and one result of this trend has been the progressive modification of the program of instruction at the United States Military Academy to keep abreast of technological developments. For example, the increased importance of electronic devices in military equipment has necessitated the lengthening of the course in electrical engineering fundamentals given at the academy to provide for greater emphasis on the basic theory underlying these devices.

Since all cadets at West Point pursue an identical program of studies, the size of the classes is rather large; the first class (in which the course in electricity is at present scheduled) comprises over 850 cadets, although each instructor teaches a section usually not exceeding 15 cadets. Naturally with such large numbers of students, teaching facilities must be quite extensive and involve many unusual problems, not the least of which is the requirement of uniformity of instruction. This is achieved by close control and co-ordination of all instructors and by laboratory apparatus and equipment which is as uniform as possible for all sections.

It is evident that the problems involved in the laboratory phases of instruction necessarily require a different approach and solution than is possible in the usual civilian college. This is particularly true for the course in electricity in which individual laboratory work is emphasized. The purpose of this article is to describe a new 140-position electronics laboratory, shown in Figure 1, especially designed to provide large-scale laboratory facilities for the instruction of cadets in electronics and communications at an introductory level.

DESIGN CONSIDERATIONS

An important feature of electrical laboratories is the supply and distribution of electrical power. For electronics experiments this may require most of the following supply sources: filament or heater voltage; plate and screen voltage; grid biasing voltage; and, depending upon the particular experiment, audio-frequency or radio-frequency signal voltages. In many laboratories these varying voltages are furnished to each student by individual power supplies and signal sources, each of which usually is operated from a 115-volt 60-cycle power circuit. The power distribution problem therefore resolves itself to furnishing a suitable number of outlets for this facility, with some additional tie lines.

In a 140-position laboratory, however, this method of supplying the array of voltages requires an excessive investment in power supply and signal source apparatus and is extravagant of bench-top space which is always at a premium. Furthermore, the storage, issue, and servicing of the large numbers of power supplies and signal sources in addition to the laboratory equipment required for the various experiments entails considerable administrative difficulties. Finally, for a basic course, much is gained by minimizing the amount of auxiliary apparatus in use by the cadets, so as to focus their attention on the fundamental electrical principles and objectives of the particular experiments performed.

To meet the special needs of the West Point laboratory, centralization was adopted for all power supplies and audio-frequency and radio-frequency signal sources in a single group of units of sufficient rating to feed 140 stations simultaneously. Additional separate signal sources sometimes required also are included for multiple use, usually by bench groups under control of individual instructors.

The successful utilization of centralized power and signal sources requires a flexible distribution system. A compromise between flexibility, space, and economic factors was reached by placing all circuits to any one bench on a common set of busses, the busses terminating on the switchboard by bench groups. This arrangement permits the simultaneous performance of different experiments on each bench. On the other extreme, the 140 cadet stations can be connected in parallel to the supply sources for common experiments by all. Conveniently located control pedestals on each bench contain circuit supervisory and overload protection for use by the in-

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The project described in this article was undertaken at the direction and under the supervision of Colonel Chauncey L. Fenton, professor of chemistry and electricity at the United States Military Academy, and the authors acknowledge his interest in and support of the project. The keen interest of the Chief Signal Officer of the Army in the ultimate objective of this laboratory—the training of future officers of the Army in basic electronics and communications theory—has been reflected in the outfitting of the laboratory with many critical and specialized items by the Signal Corps.

structors. These are supplemented by individual switches on each circuit at the cadet stations.

LABORATORY

The laboratory is about 64 feet wide by 72 feet long and includes in the major unit category a main switchboard, a 5-channel radio-frequency oscillator, and 12 laboratory benches with superstructures. As shown in Figure 2, the equipment is executed in a modern styling; it is finished in a smooth lacquer enamel with the vertical planes in a light gray color and the horizontal planes in a darker tone.

Figure 1. View of the electronics laboratory

A level of 30 foot-candles on the bench-top surfaces from indirect-lighting fixtures provides adequate illumination for reading instruments without masking the traces on the screens of cathode-ray oscillographs.

The benches are 5 feet wide by 20 feet long and each can accommodate a maximum of 12 student cadets at 6 stations on a side. The cabinets under the benches provide storage space for the instruments, electronics equipment, and cathode-ray oscillographs.

The bench units, Figure 3, are constructed of 1/8-inch steel in three sections bolted together and supported on pedestals above the bench tops. This arrangement permits practically the entire bench-top surfaces to be utilized for apparatus, and in addition provides a shelf one foot wide the full length of the bench. All wires and cables are contained within the steel trough; access for maintenance merely requires removal of the top cover. At each cadet station the distribution circuit terminals are grouped together and clearly designated by engraved legend plates. The terminals are special tri-pin jacks, described hereinafter, mounted on the grounded steel bench unit by colored plastic insulators.

The following distribution circuits terminate at each cadet station:

Number of Circuits	Type of Circuit	Circuit Designation
1	Single-wire circuit	CKT-0
3	Two-wire circuits	CKT-1 CKT-2 CKT-3
1	Three-wire circuit	CKT-4
1	Duplex convenience receptacle	115 volts alternating current
1	High-frequency coaxial cable	HF
4	Ground jacks	GND

Except for CKT-0, each wire circuit is controlled at the station by a flush-mounted tumbler switch of the type used in lighting circuits.

Figure 4 is a schematic circuit of a complete bench distribution circuit, and indicates the feeders from the switchboard entering the bench unit through the instructor's control pedestal in which are localized the magnetic circuit breakers for switching and overload protection on the bench circuits as a whole, together with neon pilot lights for supervision.

SWITCHBOARD

The totally enclosed switchboard, shown in Figure 5, comprises five bays.

The following power sources terminate in the power bay:

Fixed voltages:

115 volt alternating current, 60 cycles single phase, 225 ampere capacity
208 volt alternating current, 60 cycles single phase, 150 ampere capacity
240 volt direct current, 150 ampere capacity

Adjustable voltages:

2 120-volt 200-ampere-hour storage battery banks tapped every four volts
2 0–115 volt 60-cycle single-phase variable transformers

The storage batteries are an excellent source of plate voltage for electronics experiments and usually are connected in series for this purpose. The variable transformers of 50-ampere rating each are the counterpart of the storage batteries in flexibility for electronics and communications experiments. Circuit breakers are provided on both input (time delay) and output (instantane-

ous) to provide immediate protection. A voltage multiplier ganged with the control knob of the variable transformer is switched automatically to provide factors of 1, 4, and 10 in the indication of a 0–15 voltmeter.

An isolating transformer is connected permanently in tandem with each variable transformer.

The transfer bay provides four sets of paralleling jacks. These are particularly useful when transferring a given power supply to a group of bench circuits, especially at a high amperage. Distribution circuits to the 12 benches terminate on the distribution bay.

The audio-frequency bay is arranged for mounting of 6½ linear feet of standard 19-inch relay-rack equipment. The apparatus mounted includes a beat-frequency oscillator providing audio-frequency voltages from 20 to 40,000 cycles per second at a maximum of one watt output; two booster amplifiers useful up to 10,000 cycles per second, each with a 60-watt output; a voltage-level metering panel; a radio receiver for obtaining standard frequency transmissions from WWV (National Bureau of Standards); two loud speakers; and a patching panel for interconnecting the equipment. The apparatus on this bay is utilized as the primary source of audio-frequency power. When supplying the entire laboratory, the two booster amplifiers each are connected to feed six benches through high frequency coaxial lines and are driven by the beat-frequency oscillator. To reduce the effects of accidental short circuits (due to misconnections by cadets) an attenuator pad is placed in each of the coaxial lines being fed. (See Figure 6.)

The radio-frequency bay is arranged for relay rack mounting of equipment. A large panel carries the high-frequency terminal jacks for the coaxial lines. All coaxial lines are patched with corresponding size coaxial patch cords, with a suitable arrangement for changing from the 7/8-inch to the 3/8-inch line jacks.

PROTECTIVE MEASURES

Protective measures in laboratories are necessary and important for the safety of personnel and equipment; an added consideration in this laboratory is prevention of lost time from circuit interruptions. An improperly made connection at any one station could result in impairing the operation of the remaining 139 stations. Faults therefore must be localized quickly to preclude disruption of the entire laboratory. This is achieved by means of the magnetic-type circuit breakers located on the instructor's control pedestals which restrict faults to the respective benches at which they occur.

Personnel. By its very nature, apparatus for experimental use is exposed to personnel and the best that can be done in a laboratory is to limit the voltage sources to reasonable values; to ground properly all exposed metal panels and frameworks including switchboards and bench units; to provide conveniently located switches for removing power while making or when

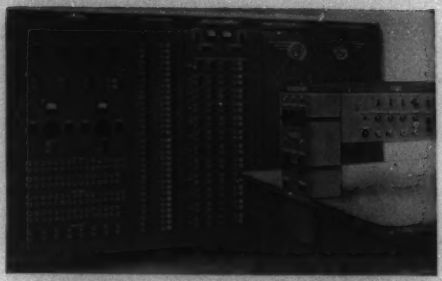

Figure 2. Main switchboard and bench unit

changing circuit connections; and to discipline instructors and students alike in the habitual use of these switches and in keeping a "hands off" attitude when power is applied to the exposed apparatus. These are standing operating procedures in the installation described.

Apparatus. For electronics apparatus it is highly desirable to limit fault currents to much smaller values than 35 amperes, the limit of the circuit breakers on the control pedestals. It has been found practicable to use tungsten-filament incandescent lamps as current-limiting devices for this purpose. One lamp is placed in series with the appropriate wire of each bench distribution circuit to be protected. Thus when a fault occurs on a particular bench, only those stations paralleled on that bench are affected, and full voltage thereby is maintained on the remaining benches.

Although the entire load current for a given bench passes through a current-limiting lamp, any voltage varia-

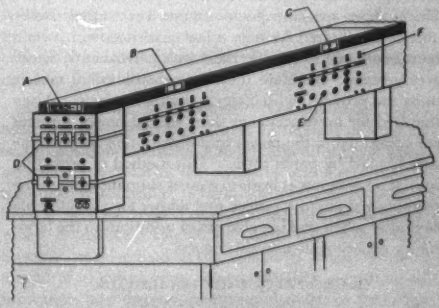

Figure 3. Bench unit details

A—Instructor's control pedestal
B, C—Cadet stations
D—Magnetic circuit breakers
E—Tri-pin jack terminal
F—Tumbler switch on individual wire circuit

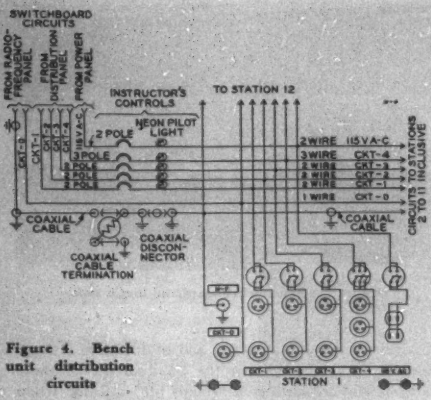

Figure 4. Bench unit distribution circuits

tion thereby introduced in the bench circuit is generally speaking negligible since the cold resistance of the lamps is only of the order of ten per cent of their hot resistance. These lamps have not been mounted permanently in the switchboard, but instead are plugged into the appropriate jack of each distribution circuit on the distribution panel of the switchboard by means of a special plug-in socket, thereby permitting complete freedom in the use of these devices.

AUXILIARY VOLTAGE SOURCES

In many electronics experiments, special supply voltages are required in addition to those permanently terminating on the main switchboard. For instance experiments on single-phase full-wave rectification require a transformer of suitable rating with a center-tapped secondary winding for distribution on a three-wire basis. Since these special voltage sources are rather bulky and often required for only a few experiments, it would be uneconomic to include them in a permanently wired arrangement; therefore they are constructed as mobile units and provided with integral circuit breakers. When required for an experiment these special power supplies are connected to the power and distribution bays on the switchboard by patch cords. This method of providing special power sources leads to a great simplification in the switchboard circuits proper and allows for considerable flexibility when making changes or additions to the laboratory experiments and procedures.

RADIO-FREQUENCY OSCILLATOR

The 5-channel radio-frequency oscillator included as a permanent part of the laboratory installation makes possible the distribution of radio-frequency energy to each of the 140 stations at a fairly high power level, and places the distribution of radio-frequency power somewhat in the same category as the distribution of 1,000-cycle power. The oscillator consists of a main rectifier power supply; a dual modulator; four identical high-frequency oscillator-power amplifier channels capable of 100 per cent amplitude modulation at a carrier level of 300-watts each with carrier frequencies from 2 to 18 megacycles per second; one 600-watt channel for carrier frequencies between 150 and 500 kilocycles per second, also capable of 100 per cent modulation. Any four of the radio-frequency channels can be operated simultaneously, with two of them independently amplitude modulated. The carrier frequencies may be controlled either by electrical master oscillators, or by quartz crystal oscillators, thereby providing any desired carrier frequency to be used in the bands enumerated in the foregoing. Crystal oscillators provide exact carrier frequencies, usually chosen at exactly 2, 10, and 18 megacycles per second, thereby facilitating quantitative measurements in experiments.

The entire installation is shielded completely with the oscillator housing as well as all other large conducting surfaces carefully bonded together and to the earth. Since the output leads from the oscillator are coaxial-type cables the spurious radiation from the entire system is of negligible proportions up to the actual cadet stations, where necessarily some of the apparatus is unshielded. This applies to tuned circuits particularly, since in elementary work much is gained pedagogically by simplifying the apparatus as much as possible—and this means no shielding.

COAXIAL DISTRIBUTION SYSTEM FOR HIGH-FREQUENCY POWER

Uniform distribution of high-frequency power is accomplished by means of the coaxial transmission line distribution circuits. Supplying an isolated load through

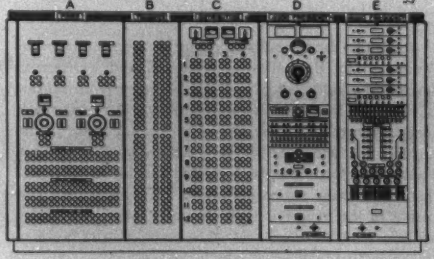

Figure 5. Main switchboard

A—Power bay, showing circuit breakers and jacks for fixed voltages, variable transformers, and storage battery taps

B—Transfer bay

C—Distribution bay

D—Audio-frequency bay, showing beat frequency oscillator, volume level meter, jacks, radio receiver, and audio power amplifiers

E—Radio-frequency bay, showing remote controls for radio-frequency oscillator and jack panels

a coaxial line merely requires that the load impedance be matched to the surge impedance of the coaxial cable to secure a maximum power transfer without frequency discrimination. When several loads are to be fed from the terminus of a single coaxial line—actual conditions on the benches may require the supply of a maximum of 12 stations—the problem is somewhat more difficult, since each of the loads must obtain its proportional share of the available power. Furthermore, 12 such coaxial lines with their multiple loads may be in use at one time in the laboratory. Impedance matching must be maintained and impedance discontinuities avoided on all the coaxial cables if the parallel operation of 140 station outlets is to be accomplished satisfactorily. Separate gas-tight 3/8-inch copper coaxial lines, ceramic insulated, of 72 ohms surge impedance connect each of the 12 benches to the radio-frequency bay of the main switchboard. At the switchboard, coaxial jacks permit the patching of the benches in any desired manner to the audio- or radio-frequency oscillators. On the instructors' control pedestals, coaxial patch-cord disconnectors are included; these are the high-frequency equivalents of switches and serve the same purpose.

The shielded termination boxes contain a 73-ohm noninductive resistor capable of dissipating 100 watts (see Figure 6) and a banana-jack arrangement which, with plug-in short-circuiting bars and resistor elements, permits a wide variety of terminations of the coaxial lines. These include shunt and series connections of the terminating resistor and L, T, or π attenuation pads. Thermocouple ammeters also may be plugged into the termination circuits.

Audio-Frequency Distribution. For many audio-frequency experiments, the loads are of the high-impedance bridging type, and the necessary power is of negligible proportions; only a definite signal voltage at a low impedance level, and of known frequency, is then required. This may be obtained in several ways. At frequencies up to 10 kilocycles per second, the lines may be left unterminated when supplied by the low internal impedance outputs of the oscillator or power amplifiers. When frequency discrimination is to be avoided the coaxial lines may be terminated in their surge impedance—73 ohms—by means of the resistors in the termination boxes. The high-impedance loads then are bridged across the 73-ohm termination. If only a few volts are required then a simple attenuator pad arrangement as shown in Figure 6 in place of the 73-ohm terminating resistor will reduce the voltage at the bench to the desired level. At the same time this attenuator provides a measure of isolation between benches so that accidental short circuits on any one bench will not affect the other stations by more than a few per cent.

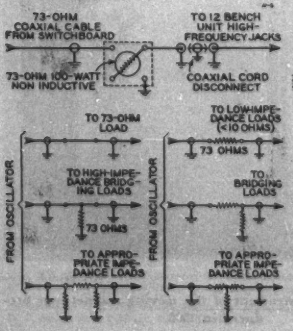

Figure 6. Methods of terminating high-frequency coaxial distribution cables

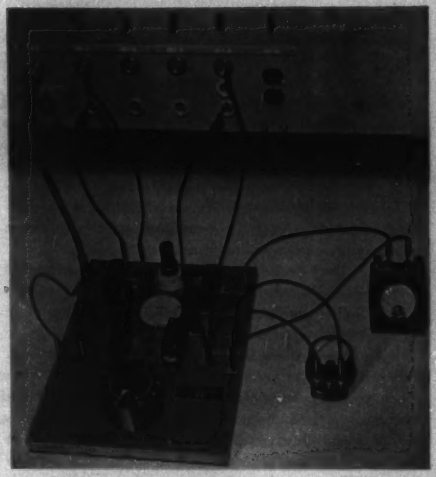

Figure 7. Electronics experiment board connected to bench unit

Radio-Frequency Distribution. The multiple distribution of radio-frequency energy on a basis of equality to 140 positions is naturally more difficult than at lower frequencies because of the effects of impedance discontinuities. Paralleling of the unequal-length coaxial lines at the switchboard requires each line to be terminated in its surge impedance; each then will present a purely resistive load to the oscillator. Since the lines are all of identical surge impedance they present equal resistances and thereby obtain equal shares of the radio-frequency power.

In basic radio-frequency experiments, two types of radio-frequency energy supplies are required: one on an equal voltage basis to all stations, and one on an equal ampere-turn basis for inductively coupled loads. One satisfactory method of furnishing equal voltages to

all stations is to terminate each coaxial line in an L pad at the termination boxes. This is necessary because the 12 multipled high-frequency jacks and the associated coaxial patch cords on each bench introduce capacitive components shunting the 73-ohm terminating resistors of each line, with the result that the voltages at the benches differ widely due to the unequal line lengths. By placing this capacitive component across the low resistance shunt arm of the L pad this effect is rendered negligible and all benches receive equal voltages; furthermore, this introduces the beneficial isolation between benches previously mentioned.

The method devised for energizing the coupling coils overcomes the effect of the 20-foot length of the benches by paralleling each coil with a capacitor to antiresonate the coil and its proportional share of the coaxial cable and junction-box capacitances. With properly chosen identical coils and capacitors at each station the entire bench circuit is resonated. Thus the coaxial distribution lines are terminated in their characteristic impedances—73 ohms—while the reactive volt-amperes in the tuned circuits are confined to the bench circuits proper. Taps are brought out on the coupling coils such that several voltages are available at a constant level at each station.

APPARATUS CONNECTIONS

The successful operation of a large electronics laboratory depends upon many factors, among which may be mentioned the purely practical one of interconnecting apparatus. This problem exists because the electrical and radio industries never have standardized upon a few types of connectors with the result that many varieties of binding posts, banana plugs and jacks, and other types of connections are furnished on commercial laboratory instruments and equipment.

At West Point a long maintained policy has been the use of tapered pin plug and jack connectors of large capacity for the power laboratories, with a smaller version suitable for electronics and communications apparatus. By using a few standardized cord lengths tipped with tapered pin plugs on both ends and providing multiple tapered pin jacks on all equipment, great flexibility of connections is possible, connections are made easily and quickly, and electrical contacts are uniformly good. Of course it is a considerable undertaking initially to provide equipment with the tapered jack. For instance, all new instruments must be provided with the multiple jacks; while on other equipment use sometimes is made, as an expedient, of strips of brass with two or three holes reamed to the proper taper fastened to the apparatus.

The terminals on the bench units also were designed to utilize the same type of tapered pin connectors, each distribution line terminal being provided with a three-hole pin-jack arrangement (thus the name tri-pin jack). The tri-pin jack body is of machined brass, chrome plated, and has the three tapered pin holes at an angle to the face of the jack. The jack bodies are fastened in color-coded insulating bushings which mount the terminals and insulate them from the grounded steel framework of the bench units. One of the simpler triode amplifier circuits is shown in Figure 7 connected to the bench unit from which the heater, plate, and signal voltages are distributed. The method of providing commercial instruments and experimental apparatus with tapered pin connectors is clearly evident; other obvious variations also are utilized extensively.

FLEXIBILITY OF PLAN

Although the problems discussed in this article are somewhat peculiar to the Military Academy in view of its mission, nevertheless they are basically the same ones encountered elsewhere. The simplicity and reliability of the method of achieving the design objective of the laboratory, that is, to provide the facilities for the efficient simultaneous instruction of over 100 cadets, each performing the same experiment, has been demonstrated by its successful operation during the past two years. Although it might appear that this laboratory is rather inflexible in view of its primary design objective, it will permit the scheduling of 12 totally different experiments concurrently—one on each of the 12 benches—and in addition it is possible to conduct each of the 12 experiments with ample facilities for 8 to 10 cadets.

It is considered likely that some features of the installation described could be incorporated profitably in the plans for the modernization or new construction of educational or industrial electronics laboratories.

Westinghouse photo

Original a-c-d-c instrument of the moving magnet type produced in 1888

Statistical Methods in Quality Control

IX. Acceptance Sampling

MUCH ACCEPTANCE INSPECTION is conducted on a sampling basis. For example, a lot of 1,000 like articles is presented to an inspector for acceptance. He selects a sample of 75 articles from the lot, and inspects them. If he finds not more than one of the articles defective, he accepts the lot; if he finds two or more of them defective, he rejects the lot. He goes through the same procedure for each of a succession of lots, as they are presented to him, one by one.

This article discusses acceptance sampling plans used in inspections performed by the method of attributes including single sampling, double sampling, and multiple sampling. It presents a number of typical "operating characteristics" of sampling plans.

Now, where sampling instead of complete inspection is used, certain errors or risks are unavoidable. One might ask, "What risks is the inspector taking in the foregoing sampling plan?," "Why not look at a sample of only 35 articles and accept the lot if no defects are found in the sample?," or "Why not merely a sample of 10?" Certainly the latter procedure would require less effort. We can get help in answering such questions by making use of certain probability laws.

It is the purpose of this article to consider some of these matters as they relate to acceptance sampling inspections performed by the "method of attributes,"[1] in which the acceptability of product is to be determined with respect to dimensions, finish, and other characteristics adaptable to nondestructive, "go-and-no-go" gauging, and visual inspections. The discussion has particular bearing on products which consist of individual articles of the same design and which are produced repetitively in quantity. Many of the principles outlined may be applied equally well to inspections performed by the "method of variables."[1]

We may speak of three types of sampling procedures: single sampling,[2] double sampling,[2] and multiple (or sequential)[2] sampling. In single sampling, only one sample of n articles is inspected in order to decide whether the lot should be accepted or rejected, and the acceptance criterion is expressed as an acceptance number, c, the permissible number of defectives in the sample. In double sampling, a second sample is permitted if the first fails, and two acceptance numbers are used; the first, c_1, applying to the observed number of defectives in the first sample alone, and the second, c_2, applying to the observed number of defectives in the first and second samples combined. In multiple sampling, third, fourth, fifth, or further samples are permitted, and at each step acceptance and rejection numbers are set forth, indicating whether the inspector should accept, reject, or take another sample.

One of the most satisfactory ways of showing risks involved in any sampling plan is to plot a curve known as the "operating characteristic" of that sampling plan. The heavy curve in Figure 1 shows such an operating characteristic for the single sampling plan mentioned at the beginning of this article, in which a sample of 75 articles is selected from each lot and inspected, and the lot is accepted if 1 or less defective articles are observed in the sample and rejected if 2 or more defectives are observed. This curve shows for any particular level of per cent defective in lots presented for acceptance what per cent of the lots will be accepted by the inspection plan. For example, if the quality presented is 1/2 per cent defective, the inspection plan will accept approximately 95 per cent of the lots, whereas if the presented quality is 5 per cent defective, the plan will accept only approximately 10 per cent of the lots. This percentage figure can be thought of as the "probability of acceptance," that is, 95 per cent means "the probability of acceptance is 0.95," or expressed another way, "the chances of acceptance are 95 in 100." The dotted curves on Figure 1 show operating characteristics for several

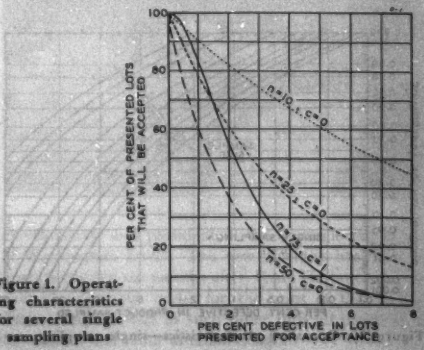

Figure 1. Operating characteristics for several single sampling plans

One of a series of articles prepared in the AIEE subcommittee on educational activities and sponsored by the AIEE subcommittee on statistical methods.

Personnel of the AIEE subcommittee on educational activities: J. Manuele, H. F. Dodge, A. L. Peterson, and R. E. Wareham.

different single sampling inspection plans which have the same acceptance number, $c=0$ (for which no defectives are allowed in the sample) but have different sample sizes. This figure simply illustrates how a change in sample size alone affects the frequency of acceptance for products having different values of per cent defective.

Figures 2 and 3* give for purposes of reference the operating characteristics of single sampling plans with sample sizes varying from 3 to 50 and with acceptance numbers of 0 and 1.

Operating characteristics likewise may be constructed for double sampling and multiple sampling plans. For example, take a double sampling plan having a first sample of 50 and a second sample of 100, with acceptance numbers of 0 and 2 ($n_1=50$, $n_2=100$, $c_1=0$, $c_2=2$). To find the operating characteristic curve value for any particular value of per cent defective, we need to figure out and sum up the chances of acceptance for all possible ways that a lot can be accepted, as illustrated in Table I.

The operating characteristics for this double sampling plan is shown by the heavy dashed line in Figure 4. On the same chart a solid line shows the operating characteristic for the single sampling plan referred to earlier, namely, $n=75$, $c=1$. These two characteristics are substantially the same, indicating the feasibility of setting up single and double sampling plans having essentially the same risks. Two other plans are shown on Figure 4 by dotted lines. The amount by which the double sampling curves on Figure 4 are above the single sampling curve $n=50$, $c=0$ (which corresponds precisely to the contribution of the first sample in the double sampling plans under discussion) shows the increase in probability of acceptance contributed by permitting a second sample.

In general, double sampling is preferred to single sampling on two counts:

1. It will provide the same protection with a smaller average amount of inspection.

2. It has certain psychological advantages, associated with the tendency to look with favor on a plan that permits a "second chance" to make good, particularly when an initial failure is marginal.

In turn, multiple sampling[4] will involve somewhat less inspection than double sampling for a given degree of protection, although often much of the gain over single sampling results from taking the second sample. Factors, other than those relating to amount of inspection, that often are controlling in the choice between double sampling and multiple sampling include: simplicity, cost of selecting samples, record keeping, training of inspectors, need for selecting samples large enough to insure representativeness, and psychological preferences of inspectors.

Systems of acceptance quality control making use of the afore-mentioned procedures have been developed, and sampling inspection tables published to accomplish certain over-all objectives. Among these systems may be mentioned one[5] which assures the inspector that no matter what quality is presented for acceptance, the *average* outgoing quality (AOQ) after inspection will not be poorer than some stated limiting value of per cent defective, designated the average outgoing quality limit (AOQL), and which attains this objective with a minimum average amount of inspection. With this procedure it is required that any lot which fails to be accepted by sample be inspected 100 per cent and cleared of de-

Table I. Computation of Probability of Acceptance—Double Sampling Plan: $n_1=50$, $n_2=100$, $c_1=0$, $c_2=2$

Number of Defectives		Probability of Acceptance		
In First Sample	In Second Sample	For 1/2 Per Cent Defective Product	For 5 Per Cent Defective Product	
0		0.779	0.082	Accepted by first sample
1	0 or 1	0.177	0.008	Accepted by second sample
2	0	0.015	0.002	
Total (probability of acceptance for the plan)		=0.971	0.092	

* Reproduced by permission from reference 4.

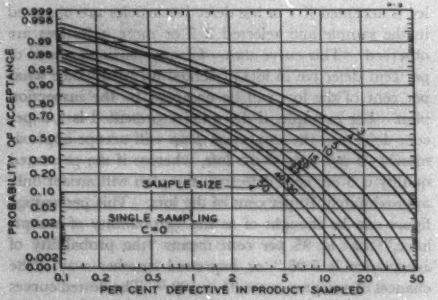

Figure 2. Operating characteristics—single sampling, c=0

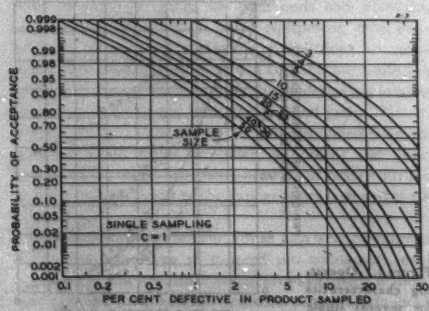

Figure 3. Operating characteristics—single sampling, c=1

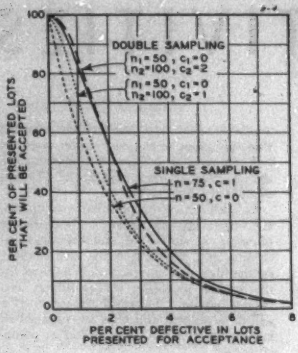

Figure 4. Comparison of single and double sampling plans

fects thus found. This type of plan is adapted particularly to use in process and final inspections in a manufacturing plant where one department produces and a subsequent department consumes the product. Another system,[5] widely used during the past three years by the armed services in the procurement of ammunition and other war matériel, carries the concept of an "acceptable quality level," that is, the maximum per cent defective which a manufacturer can be permitted continually to present for acceptance. With this system, three inspection plans are provided—normal inspection, more exacting inspection, and reduced inspection—the one to be used at any time depending on the relation between the actual quality level at that time and the acceptable quality level.

In evaluating such acceptance quality control systems, as applied to a continuing or intermittent supply, many factors must be considered. A system does not have a single operating characteristic in the usual sense, but this factor may be represented by a group of operating characteristics corresponding to the two or more sampling plans included therein. Other factors include such things as the use of recent past history, the process average quality, and the degree of stability or control, inasmuch as these systems encompass the notion of a series of lots presented over a period of time. They contain provisions for adjusting the amount and severity of inspection according to the general level of quality currently being presented for acceptance, as determined from a continuing analysis of inspection results. All such features require evaluation when comparing one system with another.

REFERENCES

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3. Sequential Sampling Inspection for Attributes, **H. A. Freeman.** *Industrial Quality Control*, September 1945, pages 3–7.

4. Acceptance–Rejection Requirements in Specifications, **H. F. Dodge.** *Proceedings* of the American Society for Testing Materials, volume 34, part 2, 1934.

5. Quality Through Inspection, **G. R. Gauss.** *Army Ordnance*, July–August 1943 pages 117–20.

Mechanical Calculator Developed at Cambridge

A gigantic calculating machine, designed to solve mathematical problems that ordinarily would take trained computers many weeks, has been developed by the Massachusetts Institute of Technology, Cambridge. This new instrument deals with problems involving rates of change among variable quantities and employs a physical system representing numbers. Problems with as many as 18 variables can be solved.

The machine, which weighs 100 tons and contains thousands of electronic tubes, approximately 150 motors, nearly 200 miles of wires, and several thousand relays, has three chief distinctions: a capacity three times that of earlier devices, greater precision, and more flexibility. The operator need not be a mathematician, but a mathematician must prepare the problem for the perforated tape which indicates the method of solving it.

The instrument was developed by scientists including Doctor S. H. Caldwell (A '27) associate professor of electrical engineering at the institute and a director of the institute's analysis center, and Doctor Vannevar Bush (F '42) director of the Office of Scientific Research and Development and president of the Carnegie Institution of Washington, D. C. The new machine has been in operation since six months after Pearl Harbor. It has worked out range tables for the guns of the United States Navy as well as such other difficult problems as fire control and radar antenna design.

INSTITUTE ACTIVITIES

Official Nominees Announced for 1946–47

J. E. Housley, district power manager, Aluminum Company of America, Alcoa, Tenn., was nominated for the AIEE presidency for the year 1946–47 by the nominating committee at its meeting in New York, N. Y., January 22, 1946. Others named on the official ticket of candidates for the Institute offices that will become vacant August 1, 1946, are:

For Vice-Presidents

E. W. Davis, chief electrical engineer, Simplex Wire and Cable Company, Cambridge, Mass. (North Eastern District, number 1).

O. E. Buckley, president, Bell Telephone Laboratories, New York, N. Y. (New York City District, number 3).

T. G. LeClair, staff engineer, Commonwealth Edison Company, Chicago, Ill. (Great Lakes District, number 5).

R. F. Daaner, general superintendent, Oklahoma Gas and Electric Company, Oklahoma City (South West District, number 7).

C. F. Terrell, vice-president, Puget Sound Power and Light Company, Seattle, Wash. (North West District, number 9).

For Directors

J. F. Fairman, vice-president, Consolidated Edison Company of New York, New York, N. Y.

R. T. Henry, chief electrical engineer, Buffalo (N. Y.) Niagara and Eastern Power Company.

E. F. Yerkes, engineer of equipment and buildings, General Electric Company, Philadelphia, Pa.

For Treasurer

W. I. Slichter, professor emeritus, electrical engineering, Columbia University, New York, N. Y.

The nominating committee, in accordance with the constitution and bylaws, consists of 15 members, one selected by the executive committee of each of the ten geographical Districts, and five selected by the board of directors from its own membership.

The constitution and bylaws of the Institute require publication in *Electrical Engineering* of the nominations made by the nominating committee. Provision is made for independent nominations as indicated in the following excerpts from the constitution and bylaws:

Constitution

Section 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District covered.

Bylaws

Section 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (Constitution), must be received by the secretary of the Nominating Committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the nominating committee in accordance with article VI of the Constitution and sent by the secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

BIOGRAPHICAL SKETCHES OF NOMINEES

To enable those Institute members not acquainted personally with the nominees to learn something about their engineering careers and their qualifications for the Institute offices to which they have been nominated, brief biographical sketches are scheduled for inclusion in the "Personal" columns of the March issue.

Winter Convention Report to Appear in March Issue

As this issue goes to press the Institute's 1946 winter convention gets under way at New York, N. Y. Early indications are that this convention is continuing the successful record of prewar years in spite of the inevitable effects of the war. Registration for the first two days totaled 1,681 compared with 1,059 for the first two days of the 1942 convention and with 1,278 for the similar period of the 1941 convention. The March issue of *Electrical Engineering* will contain the full report of the convention.

Summer Convention Planned to Be Outstanding

The various committees assigned to activities for the AIEE summer convention to be held in Detroit, Mich., June 24–28, 1946, with headquarters in the Hotel Statler, are effecting plans to make the meeting an outstanding event in the Institute's history. The removal of wartime restrictions will permit a return to normality, and there is promise that this convention will embrace many desirable features, which during the war, of necessity, were eliminated.

Under the direction of S. M. Dean (M '41) chairman, T. G. Glenn (M '38) vice-chairman, and W. F. Wetmore (M '43) secretary-treasurer, the following committee chairmen, with their respective committees are functioning to insure a long-remembered meeting.

M. A. Bergdahl	Hospitality
D. D. Chase	Sports
H. W. Collins	Hotels
A. J. Koetnier	Publicity
A. E. Kreigsmann	Meetings and papers
W. J. Piper	Information and transportation
V. J. Snyder	Finance
R. C. Spaulding	Inspection trips
F. R. Temple	Registration
(Mrs.) M. A. Bergdahl	Women's hospitality

Information on the scope and text of technical papers to be presented is not available at this date, but it can be assumed that this phase of the convention activities will maintain its position of importance to the electrical engineer and to the development of the art.

In addition to the president's reception, the hospitality and sports committees are planning a variety of entertainment including golf, tennis, boating, and smoker, for the men, and corresponding features for the women including bridge-dinner, and theater parties. Industrial inspection trips will be arranged, and trips are planned to historic Greenfield Village and other points of interest.

Planning Committee Hires Secretary

To expedite the work that it has undertaken in the study and evaluation of AIEE activities and professional relationships, the AIEE committee on planning and co-ordination secured the approval of the board of directors at its October 1945 meeting to establish a temporary full-time paid staff of one person to act as assistant secretary for the committee. Accordingly, in December the committee acquired the services of William H. Schlasman (A '25) who will devote his entire time to the committee's current project (*p. 86*).

A full report covering the 1946 winter convention conference sponsored by the committee on planning and co-ordination tentatively is scheduled for publication in the March issue of *Electrical Engineering*. The stated purpose of this conference was to accommodate the presentation of preliminary reports and tentative proposals drawn up by the committee and its subcommittees, and to provide opportunity for

Future AIEE Meetings

South West District Meeting
San Antonio, Tex., April 16–18, 1946

North Eastern District Meeting
Buffalo, N. Y., April 24–26, 1946

Southern District Meeting
Asheville, N. C., May 14–16, 1946

Summer Convention
Detroit, Mich., June 24–28, 1946

Pacific Coast Convention
Seattle, Wash., in week of August 26–30, 1946

Great Lakes District Meeting
Fort Wayne, Ind., September 25–27, 1946

interested Section representatives and other AIEE members to participate directly in an open general discussion.

Vannevar Bush Receives 1946 Washington Award

Doctor Vannevar Bush (A '15, F '24) president of The Carnegie Institution of Washington (D. C.) and director, Office of Scientific Research and Development, has been elected the recipient of the Washington Award for 1946.

The Washington Award was established in 1916 by Past President Alvord of the Western Society of Engineers, Chicago, Ill., and is presented by the Washington Award Commission, composed of nine representatives of Western Society of Engineers and two each from American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE, to the engineer who has done some outstanding work or whose services in general have been directed toward promoting the public good. Presentation will be made at a joint dinner meeting of the participating societies February 20, 1946.

A biography of Doctor Bush is given elsewhere in this issue.

SECTION . . . . . .

E. P. Coles Honored By North Carolina Section

At the November 1945 meeting of the AIEE North Carolina Section resolutions of congratulation were tendered E. P. Coles (F '35) retired, upon his 50th year of affiliation with the Institute. Mr. Coles joined the Institute in 1895 while employed as a test man with the General Electric Company, Schenectady, N. Y. He is credited with outstanding work in the electrification of the textile industry in North Carolina and South Carolina, and with taking an important part in the development of the power industry in that section.

In its resolution, the Section expressed its gratitude to Mr. Coles for "the generous contribution of his time and ability throughout the life of the Section. . . ."

Sharon Section Observes 20th Anniversary of Founding

The 20th anniversary of the founding of the Sharon (Pa.) Section, AIEE, was observed December 11, 1945, in that city. Doctor Joseph Slepian (F '27) associate director of research, Westinghouse Electric Corporation, who spoke at the organization meeting in 1926 on "Power Flow in Electric Machinery" spoke also at the anniversary meeting on the topic, "Development of Atomic Energy." He confined his remarks to the use of atomic power for military purposes under the auspices of the United States Government. Preceding Doctor Slepian's address A. D. Forbes (M '42) chairman of the group, introduced W. M. Dann (F '26) first chairman of the organization, who gave a brief history of the formation of the Section.

It was in November 1925 that a group of local Sharon men petitioned the AIEE to organize a Section in Sharon. That petition was approved on December 11, 1925.

Boston Section Forms New Technical Group

The new technical group on instruments and measurements of the Boston Section, AIEE, formed in 1945, is the fifth technical group to be organized by that Section; the other groups are electric machinery, electronics, insulation, and power systems. Professor C. L. Dawes (F '35) associate professor of electrical engineering, Harvard University, Cambridge, is chairman of the new technical group. Meetings were held in April and October. Doctor G. S. Brown (A '33) associate professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, spoke on "Servomechanism Applications and Principles of Operation," December 4, 1945.

Scheduled for the year 1946 are talks by P. L. Bellaschi (F '40) development engineer, Westinghouse Electric Corporation, Sharon, Pa., on "Surge Generators and Their Contribution to Electrical Engineering" February 26, and L. H. Hutchins, Jr., Simplex Wire and Cable Company, on "Electrical Measurements in a Cable Factory," March 26.

DISTRICT . . . . . .

South West, North Eastern District Meetings in April

Two AIEE District meetings will be held in April 1946. They are the South West District (7) meeting scheduled for April 16–18 in San Antonio, Tex., and the North Eastern District (1) meeting to be held in Buffalo, N. Y., April 24–26. Arrangements are being made for full programs of technical sessions which will include papers, entertainment, sports, and trips.

Details on the coverage of the technical papers are not yet available, but it is anticipated that this feature of the programs in both cities will measure up to its past record and will prove of inestimable value to electrical engineers in attendance. The full programs of papers and events will be published in subsequent issues of *Electrical Engineering*.

PERSONAL . . . .

Philip Sporn (A '20, M '26, F '30) executive vice-president, American Gas and Electric Service Corporation, New York, N. Y., has been awarded the Edison Medal for 1945 "for his contributions to the art of economical and dependable power generation and transmission." Mr. Sporn, who was born in Galicia in 1896, holds the degree of electrical engineer from Columbia University (1917). From 1917 to 1919 he was in the test department of the Crocker-Wheeler Electric Manufacturing Company, and in 1919 joined the staff of Consumers Power Company, Jackson, Mich., engaging in station and substation design work. He became associated with the American Gas and Electric Service Corporation in 1920 and has progressed through positions of protection engineer, communication engineer, transmission and distribution engineer, station engineer, chief electrical engineer, up to his present position of executive vice-president and chief engineer or director of 15 subsidiaries of the parent organization. In 1928 he won the AIEE national first prize in the field of engineering practice for his paper, "Rationalization of Transmission System Insulation Strength." He has been a consultant of the War Production Board and among other services, prepared a comprehensive report on the use of silver as a substitute for copper and aluminum as electrical conductors. He is a member of American Society of Mechanical Engineers, American Society of Civil Engineers, American Society for Testing Materials, Franklin Institute, and other societies. He has presented before the AIEE, associations, and in technical and economic journals a long list of engineering papers. He has been a member of many AIEE committees, including, power transmission and distribution, 1927–46, chairman 1941–43; award of Institute prizes, 1942–43; Standards, 1941–43, and Lamme Medal, 1944–47.

J. F. Fairman (A '20, F '35) formerly assistant vice-president, Consolidated Edison Company of New York (N. Y.), Inc., has been elected vice-president in charge of production and operation. Born in Big Rapids, Mich., Mr. Fairman was gradu-

Philip Sporn

ated from the University of Michigan with the degree of bachelor of science in electrical engineering (1918) and master of science (1921). There he served as instructor in electrical engineering from 1919 to 1922, and in the latter year was made assistant professor of electrical engineering. Three years later he joined the Brooklyn (N. Y.) Edison Company as assistant outside plant engineer and was made outside plant engineer and assistant electrical engineer (1926) and electrical engineer (1932) and following the merger of the various companies into the Consolidated Edison company he became electrical engineer for the system. On December 1, 1940, he was elected assistant vice-president for design, inventory, purchasing, and stores. Mr. Fairman is AIEE vice-president for the New York City District (3). He has been active in Section affairs, holding the offices of secretary, 1937–38, and chairman, 1940–41, as well as that of District secretary, 1937–38. He has served on many AIEE committees, including planning and co-ordination, of which he is chairman, 1945–46; technical program, 1945–46; executive, 1944–46; finance, 1944–46; board of examiners, 1941–44; education, 1941–42, and safety codes, 1931–34. Since 1938 he has been an AIEE representative on the Engineers' Council for Professional Development. He has served also on the electrical equipment committee of the Edison Electric Institute, and has held the office of president of the New York State Society of Professional Engineers.

Robin Beach (A '15, F '35) head of the department of electrical engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., resigned January 1, 1946, to devote his entire time to consulting engineering practice. Professor Beach was graduated from New Hampshire University with the degree of bachelor of science in electrical engineering in 1913 and received the degree of electrical engineer in 1922. In the latter year he received also a master-of-science degree in physics from New York University. Immediately upon graduation in 1913 Professor Beach began his teaching career which was to take him to the University of Illinois, Urbana; Texas Agricultural and Mechanical College, College Station; Norwich University, Northfield, Vt.; until in 1918 he became associate professor of electrical engineering at the Polytechnic Institute of Brooklyn. Later as acting head of the department he supervised the development of an electrical communications laboratory. In 1927 he was appointed professor of electrical engineering and in 1930 head of the department. Since 1932 he has been an associate in the consulting engineering firm of McCrossin and Company, New York, N. Y., handling the electrical aspects of the firm's work. In June 1944 he went on an extended leave of absence from Polytechnic Institute and in September 1944 organized his own consulting engineering firm of Robin Beach Associates, Brooklyn, to handle work growing out of war requirements in industry. He will continue with this enterprise and retain his association with McCrossin and Company. Professor Beach has been very active in Institute affairs, having served on numerous committees, such as production and application of light, education, technical program, Alfred Noble Prize, 1943–47, Lamme Medal, 1943–46, safety, 1944–46, board of examiners, 1941–42, 1945–46. At present he is a representative of the Institute on the United States national committee of the International Commission on Illumination, 1937–46.

Vannevar Bush (A '15, F '24) president, Carnegie Institution of Washington (D. C.) and director, Office of Scientific Research and Development, has been elected the recipient of the 1946 Washington Award. Doctor Bush, a native of Massachusetts, was graduated from Tufts College with the degrees of bachelor and master of science in 1913; he received honorary doctorates from that institution and from nine other leading colleges and universities. He has been honored with the Levy Medal of the Franklin Institute (1928), AIEE Lamme Medal (1935), Holley Medal of the American Society of Mechanical Engineers, and the John Scott Medal of the Philadelphia City Trustees (1943). Doctor Bush has been engaged in many enterprises —General Electric Company, Schenectady, N. Y., on the faculty of Tufts College (Mass.) as consulting engineer, American Radio and Research Corporation, Medford Hillside, Mass., and dean of engineering, Massachusetts Institute of Technology, Cambridge. He was elected president of the Carnegie Institution of Washington in 1939 and in 1940 the late President Roosevelt appointed him chairman of the National Defense Research Committee and director of the Office of Scientific Research and Development in 1941. His society affiliations include membership in the American Association for the Advancement of Science, American Physics Society, American Academy of Arts and Sciences, American Philosophical Society, American Society of Mechanical Engineers, and the Society for the Promotion of Engineering Education. He has been very active in AIEE affairs, and has served on many committees including: Edison Medal, 1933–38; Lamme Medal, 1936–39, chairman, 1938–39; board of directors, 1937–41; education, 1928–29, and research, 1924-30 and 1939–41.

W. H. Schlasman (A '25) formerly with J. H. Bunnell and Company, Inc., New York, N. Y., has been appointed to a temporary position on the AIEE staff as assistant secretary for the committee on planning and co-ordination (see page 84). Mr. Schlasman was born in Reading, Pa., in 1897, and was graduated from Lehigh University (1920) with a degree in mechanical engineering and from Yale University (1926) with a master-of-science degree in electrical engineering. He joined the staff of the long lines department, American Telephone and Telegraph Company, New Haven, Conn., in 1920 and remained until 1926. From the latter year until 1932 he was associated with electrical research products division, Western Electric Company, New York. Subsequently Mr. Schlasman was for short periods with the American Newspaper Publishers Association, Federal Communications Commission, and the New York *Times* in the operation of facsimile transmission over telephone circuits. Following an association of nearly five years with Fidelity and Casualty Company, New York, Mr. Schlasman served as telephone engineer with the Army Signal Corps on Governors Island, N. Y. From the latter part of 1942 to December 1944 he was technical writer and then editor for Sperry Gyroscope Company, Brooklyn, N. Y. In December 1944 he joined Bunnell and Company, Inc., New York, and was appointed engineer in charge, specifications and publications.

V. B. Bagnall (M '38) formerly circuit layout engineer, long lines engineering department, American Telephone and Telegraph Company, New York, N. Y., and more recently colonel, Signal Corps, Army of the United States, has been released from active duty and has returned to his former company as division plant superintendent of the long lines for the territories of Maryland, Virginia, West Virginia, and the District of Columbia. Colonel Bagnall, who received a bachelor-of-science degree from the University of Wisconsin (1927), and a master-of-science degree from New York University (1933), first entered the employ of the telephone company in 1927 and was assigned to the long lines department, Chicago, Ill. A year later he was transferred to the long lines department in New York. In 1942 he was ordered to active duty with the Signal Corps as captain and later was promoted to major (1942), lieutenant colonel (1943), and colonel (1944). In December 1942 Colonel Bagnall was appointed chief, communications engineering branch, Army Communications Service, Office of the Chief Signal Officer. He was awarded the Bronze Star and the Legion of Merit.

E. I. Pollard (A '35, M '45) design engineer, a-c generator engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed to the engineering staff of the Ridgway plant of the Elliott Company, Jeannette, Pa. Mr. Pollard received a bachelor-of-science degree from the University of Nebraska (1929) and a master-of-science degree from the University of Pittsburgh (1935). He entered the employ of the Westinghouse company in 1928.

C. E. Parks (A '40) relay engineer, power department, Public Service Company of Indiana, Indianapolis, recently was elected president of the Indiana Engineering Council.

J. L. Dow (M '25) director of switching development, Bell Telephone Laboratories, Inc., New York, N. Y., retired in 1945 after a period of 38 years with the company. Following his graduation from the Kansas State Agricultural College in 1906 with a bachelor-of-science degree in electrical engineering, Mr. Dow went to Western Electric Company, Chicago, Ill., as an engineering student. Subsequently, he served for several years in Hawthorne, Ill., and in 1916 he took the position of circuit development engineer in New York. In 1925 he was put in charge of the circuit laboratory testing manual and machine switching telephone circuits of the Bell Telephone Laboratories. In 1921 he became laboratories engineer for the local systems department, and in 1943 he was named director of switching development. **F. J. Scudder** (M '25) systems development engineer, has been appointed director of switching development. Mr. Scudder joined the New York Telephone Company in 1905 and five years later became associated with the dial telephone switching program of the Western Electric Company. In 1918 he became a member of the technical staff of Western Electric Company and the Bell Telephone Laboratories, Inc.

I. H. Osborne (A '05, M '38) chief electrical engineer, Federal Shipbuilding and Dry Dock Company, Kearny and Port Newark, N. J., retired December 31, 1945. Mr. Osborne, a native of Waterbury, Conn., studied electrical engineering at Pratt Institute. For two years he was with the General Electric Company at Lynn, Mass., and for 17 years was associated with the Newport News (Va.) Shipbuilding and Dry Dock Company, serving as draftsman, assistant electrical engineer and later acting electrical engineer. In 1919 he was made electrical engineer of the Federal Shipbuilding and Dry Dock Company. Mr. Osborne has served on the following AIEE committees: marine (applications to marine work and marine transportation), 1918–46, chairman, 1941–43; technical program, 1941–43, and Standards, 1941–43. **R. W. Erickson** (M '20) assistant electrical engineer has been named chief electrical engineer. From 1907 to 1912 he served an apprenticeship with the Harlan and Hollingsworth Corporation, Wilmington, Del., and for the next two years was associated with E. I. du Pont de Nemours and Company, Wilmington. Subsequently he was employed at the Philadelphia (Pa.) Navy Yard, and then followed a period of nearly two years with the Sun Shipbuilding and Dry Dock Company, Chester, Pa. In 1917 he was appointed chief electrical draftsman and assistant to the electrical engineer for the Federal Shipbuilding Company. He directed the installation of the electric system in the Kearny yard.

P. R. Knapp (A '18, F '38) assistant general superintendent, Toledo (Ohio) Edison Company, has been promoted to general superintendent. Mr. Knapp was born in West Boylston, Mass., and was graduated from Worcester Polytechnic Institute (1917) with a bachelor-of-science degree in electrical engineering. He joined the Toledo Edison Company, then known as the Toledo Railways and Light Company in 1917, and after serving in World War I he rejoined the Toledo company in 1919. The next year he was placed in charge of construction planning and designing. Subsequently, he was appointed assistant superintendent of the electric distribution and transmission department and then superintendent. He held this position until 1943 when he was made assistant general superintendent. Mr. Knapp was a member of the AIEE committee on power transmission and distribution, 1942–43.

K. J. Affanasiev (M '41) who recently completed work with Columbia University's division of war research as research and project engineer with Airborne Instruments Laboratory, Mineola, N. Y., has joined the staff of the Federal Communications Commission as principal engineer. Mr. Affanasiev, a native of Russia, received a bachelor-of-science degree in electrical engineering (1932) and a master-of-science degree in electrical engineering (1935) from the University of Wisconsin. Early in his career he worked for the Pacific Telephone and Telegraph Company, in Seattle, Wash., and San Francisco, Calif., and later for the Wisconsin Public Service Commission. In 1935 he became associated with Federal Communications Commission and served as associate telephone engineer and telephone engineer. In 1939, as engineer, he undertook special studies for the Pennsylvania Water and Power Company, Baltimore, Md., and remained with that utility until he engaged in the war research program of Columbia University, New York, N. Y.

W. L. Cisler (M '35) formerly chief engineer of power plants, Detroit (Mich.) Edison Company, and more recently United States chief in charge of German utilities under the Allied Control Authority has resumed his former duties with the Detroit utility. During World War II he was associated with the Office of Production Management, Washington, D. C., and with the power section of the Office of War Utilities. He has served on the following AIEE committees: power generation, 1935–43, chairman, 1940–42, technical program, 1940–42, and Standards, 1941–42.

F. A. Fleming (M '43) who specializes in the supply and repair of scientific industrial instruments Ottawa, Ontario, Canada, has been appointed technical representative in Ottawa for R. H. Nichols, Toronto, Canadian agents for Cambridge Instruments, Evershed and Vignoles Limited, and Ernest Turner Instruments Limited, England.

L. H. Cleary (A '20, F '42) consulting engineer, Weschler and Cleary, Washington, D. C., was appointed to the new post of technical director, National Electrical Contractors Association, Washington, effective January 1, 1946. Mr. Cleary has a long record in the electrical contracting industry. His more recent assignments include the design of the electrical distribution system for the assembly and repair shop at the United States Marine Corps base at Quantico, Va., and the United States Signal Corps School Project, Arlington, Va. A native of Connecticut, Mr. Cleary received his bachelor-of-science degree in electrical engineering in 1916 from the engineering school of the Catholic University of America. At present he is serving as secretary-treasurer of the AIEE Washington Section. He also is a member of the Society of American Military Engineers and is treasurer of the National Society of Professional Engineers.

O. K. Coleman (M '37) has resigned as assistant to vice-president and as chief engineer of the American Gas and Electric Service Corporation, New York, N. Y., and has moved to Mexico, Ind., where he will look after his farming interests and engage in consulting work. He has been retained by the Duncan Electric Manufacturing Company, Lafayette, Ind., and will be available for that firm on field applications. In 1923 he joined the American Gas and Electric property and has served as meter superintendent, field meter engineer, and meter engineer. Mr. Coleman served as chairman of the Edison Electric Institute's committee on the revision of the National Electrical Metermen's Handbook. He assisted in bringing about the standardization of outdoor meter mountings and associated equipment.

G. A. Kelsall (A '10) member of the technical staff, Bell Telephone Laboratories, New York, N. Y., retired in 1945 after a 33-year service record with the company. Mr. Kelsall, a native of Louisville, Ky., was graduated from Rose Polytechnic Institute with the degree of bachelor of science in electrical engineering in 1906. Early in his career he was employed by Louisville Railway Company, General Electric Company, and Indiana Steel Company, Gary, Ind. In 1909 he went to Michigan Agricultural College, East Lansing, as an instructor in electrical engineering. Three years later he joined the Western Electric Company, New York. Beginning with 1917 his work was directed to fundamental studies of magnetic materials. He has investigated more than 2,500 alloys.

L. A. Buese (A '31) chief design engineer, Hawaiian Electric Company, Limited, Honolulu, Hawaii, has been appointed vice-president, executive engineer, and director. Mr. Buese early in his career served as electrician and foreman for the street rail-

way in Bisbee, Ariz., and as electrician in Salt Lake City, Utah. In 1921 he became affiliated with the Los Angeles (Calif.) Gas and Electric Corporation and was lineman, assistant foreman, foreman, electrical protection engineer, and assistant superintendent of electrical distribution. Later he went to Honolulu and in 1938 served as electrical engineer, Hawaiian Electric Company. Subsequently he became design engineer and chief design engineer.

R. K. Honaman (A '16, F '36) formerly director, school for war training, Bell Telephone Laboratories, Inc., New York, N. Y., is now director of publication. In 1919 he became a member of the technical staff of the transmission development department, American Telephone and Telegraph Company, New York, and in 1934 was named protection methods engineer, Bell Telephone Laboratories, Inc. During World War I he was engaged in Washington, D. C., in studies relating to airplane engine design. In World War II he organized the school for war training for the laboratories and was its director until May 1945 when he was named assistant director of publication.

H. R. Anderson (A '27, M '36) formerly electrical engineer, system planning section, Bonneville Power Administration, Portland, Oreg., and a reserve officer, recently on active duty with the Engineer Corps, headquarters, Sixth Army, has returned to his former position. Mr. Anderson, who received a bachelor-of-science degree in electrical engineering from Iowa State in 1922, has been identified with the Great Western Power Company, San Francisco, Calif., Loup River Public Power District, Columbus, Nebr., and with the United States Engineers at the Fort Peck (Mont.) Dam. In 1938 he joined the staff of the Federal Power Commission, Washington, D. C.

A. A. Emlen (A '28) vice-president, American Transformer Company, Newark, N. J., is taking charge also of engineering and related activities of the company. A graduate of the University of California with a bachelor-of-science degree in electrical engineering, Mr. Emlen was associated first with the Western States Gas and Electric Company, Placerville, Calif., and then with the General Electric Company in Schenectady, N. Y., and Pittsfield, Mass. In 1927 he joined the engineering department of the American Transformer Company.

E. G. Eidam (A '18) consulting engineer and formerly chief telephone engineer, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., retired January 1, 1946, after more than 40 years with the company. Mr. Eidam, was born in Blue Island, Ill., in 1879 and was graduated in mechanical engineering from the University of Illinois. In 1904 he joined the staff of the Stromberg-Carlson Telephone Manufacturing Company and was engaged first in the design and manufacture of electric apparatus. He rose to the positions of assistant chief engineer, chief telephone engineer, and in 1944 was made consulting engineer.

B. W. Creim (A '20, F '31) assistant chief engineer, Bonneville Power Administration, Portland, Oreg., recently was appointed regional power manager of the United States Bureau of Reclamation, Sacramento, Calif. Mr. Creim, a native of Chicago, Ill., attended George Washington University. After a short period with the United States Bureau of Standards, Washington, D. C., he joined the staff of the Bureau of Power and Light, City of Los Angeles, Calif., remaining in this assignment until 1927. In the latter year he took a position as chief electrical engineer with the Modesto (Calif.) Irrigation District, and in 1936 was appointed senior electrical engineer for the Rural Electrification Administration, Washington, D. C. In 1939 he was appointed principal engineer in charge of the project construction section, engineering division, Bonneville Dam project. Mr. Creim served recently with the United States Navy.

C. L. Sampson (A '25, M '39) assistant vice-president, Northwestern Bell Telephone Company, Omaha, Nebr., since July 1, 1944, has been promoted to general manager for the State of Iowa and has transferred to Des Moines, Iowa. A native of Minneapolis, Minn., Mr. Sampson was graduated from the University of Minnesota with the degrees of bachelor of science in electrical engineering (1923) and master of science in electrical engineering (1925). He was an instructor in electrical engineering at the University of Minnesota, Minneapolis, before becoming engineer of transmission, protection, and plant extension, Northwestern Bell Telephone Company for the Iowa area in 1928. In 1939 he was made plant engineer for Minnesota, leaving that position in 1940 to become chief engineer in Iowa.

L. E. Messinger (A '30, M '44) president and managing director, Canadian Line Materials, Limited, Toronto, Ontario, is also president, Selenium Corporation of Canada, following a recent appointment. Mr. Messinger served as electrical engineer of the Economy Fuse and Manufacturing Company, Chicago, Ill., just before World War I in which he was lieutenant, Engineer Corps, Army of the United States. After the war he returned to that company. In 1925 he became sales engineer, Line Material Company, Milwaukee, Wis., and in 1929 was made president and managing director, Canadian Line Materials, Limited, Scarboro Junction, Ontario.

R. A. Schatzel (A '28) formerly director of research, General Cable Corporation, Bayonne, N. J., is now vice-president and director of engineering, Rome (N. Y.) Cable Corporation. He first was employed in the research laboratory of the General Electric Company, Schenectady, N. Y., and in 1924 joined the Rome company to do research and development work. The next year he was made assistant director of research, and in 1927 he became technical director of the Rome wire division of the General Cable Corporation. Mr. Schatzel returned recently from a visit to Germany where he was a member of a group of scientists sent to Europe for an investigation of German technology. During World War II Mr. Schatzel served as chairman of an industry-advisory committee of the War Production Board, and also as War Production Board representative on the war committee for dielectrics.

W. R. Herod (A '20) formerly executive vice-president, International General Electric Company, New York, N. Y., has been elected president and a director. Mr. Herod was graduated from the Sheffield Scientific School, Yale University, in 1918. He joined the General Electric Company, Schenectady, N. Y., in 1919 later serving as special assistant in the construction-engineering department. In 1929 he was transferred to the International General Electric Company. From 1934 to 1937 he was assistant to the managing director, Associated Electrical Industries, London, England, and in 1937 returned to New York as vice-president of International General Electric. Called to active service with the Army Air Forces in 1942 as a lieutenant colonel, he shortly was promoted to colonel and served with the Air Technical Service Command, Wright Field, Dayton, Ohio, and at Detroit, Mich. He was elected executive vice-president on his return to the company in 1945.

W. F. Lebo (A '20) formerly acting chief engineer, Public Service Commission of Indiana, Indianapolis, has been appointed chief engineer. Mr. Lebo was graduated from the school of electrical engineering, Purdue University. He worked for short periods for the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., and the Merchants Heat and Light Company, Indianapolis, before 1919 when he was named senior engineer for the commission. Mr. Lebo served on the legislative committee, AIEE Central Indiana Section, 1944–45.

C. A. Molsberry (A '29) formerly general superintendent of production, United Illuminating Company, New Haven and Bridgeport, Conn., has been appointed system planning engineer. **M. F. Beebe** (A '41) formerly superintendent of distribution, succeeds Mr. Molsberry. **W. J. Oakley** (A '43) assistant superintendent of distribution, New Haven division, has been named superintendent of distribution.

C. W. DeForest (A '07, F '36) who retired in 1945 after 43 years with the Columbia Engineering Corporation, New York, N. Y., and its affiliate, the Cincinnati (Ohio) Gas and Electric Company, now is serving as United States chief in charge of German utilities under the Allied Control Authority. Early in his career Mr. DeForest was associated with the Brooklyn (N. Y.) Edison Company, United Electric Light and Power Company, New York, and General Electric Company, Schenectady, N. Y. He was appointed vice-president of the Columbia Power Company in 1925 when that was formed as a subsidiary of the Columbia Gas and Electric Corporation, and later became chief engineer of the Columbia Engineering and Management Corporation, a company later abandoned. When in 1938 the Columbia Engineering Corporation was formed, he was given charge of the electrical division. At the the time of his retirement he was vice-president.

H. B. Bryans (M '17, F '18) executive vice-president, Philadelphia (Pa.) Electric Company, has been re-elected to serve a third term as president of the American Standards Association. **F. R. Lack** (M '37) vice-president and manager, radio division, Western Electric Company, Inc., New York, N. Y., was elected vice-president. **E. C. Crittenden** (A '19, F '44) assistant director, National Bureau of Standards, was made chairman of the Standards Council. **L. F. Adams** (A '09, F '42) assistant to the vice-president, General Electric Company, Schenectady, N. Y., was made vice-chairman of the Standards Council.

L. F. Eaton (A '45) formerly assistant general manager, Montaup Electric Company, Brockton, Mass., has been appointed manager of the Woonsocket (R. I.) division of the Blackstone Valley Gas and Electric Company. He had been associated with Brockton (Mass.) Edison Company and Stone and Webster Service Corporation. Before going to Woonsocket he served as assistant to the vice-president in charge of electric operations of the Blackstone Valley property in Pawtucket, R. I.

L. A. Gary (A '12, M '26) formerly exchange transmission engineer, Pacific Telephone and Telegraph Company, San Francisco, Calif., retired October 1, 1945. Mr. Gary was born in Zanesville, Ohio, June 5, 1883, and was graduated from Case School of Applied Science in 1904 with a bachelor-of-science degree in electrical engineering. Mr. Gary first was employed by the San Francisco (Calif.) Gas and Electric Company, and from 1905 to 1911 by the Western Electric Company, San Francisco. For the next two years he was engaged in his own engineering and contracting business. In 1913 he went with the Pacific Telephone and Telegraph Company. For the past 20 years he has served in the transmission department.

C. V. Armstrong (A '36) formerly electrical engineering group, general engineering department, Standard Oil Development Company, Elizabeth, N. J., and more recently lieutenant, United States Coast Guard has been placed on inactive duty by the Coast Guard Reserve after spending three years on the design and test of ship's machinery, especially turbine-electric propulsion machinery. He now is engaged in research and development in electrochemical applications for Bell and Gossett Company, Morton Grove, Ill.

S. B. Lent (M '43) formerly assistant electrical engineer, Boston (Mass.) Elevated Railway, has been appointed electrical engineer. Mr. Lent became associated with the Boston Elevated Railway in 1922, later being placed in charge of the electrical engineering division laboratory. In 1938 he assumed the duties of engineer, and became a consultant to the rolling stock and shops department on all electrical problems.

R. A. Nielsen (M '45) formerly research engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been named head of the company's new Pacific coast high-frequency laboratory, Los Angeles, Calif. Doctor Nielsen was born in Portland, Oreg., and was graduated from Stanford University as a bachelor of arts in 1933, a master of arts in 1934 and a doctor of philosophy in 1937, all degrees being awarded in physics. He is a member of the American Physical Society.

W. G. Ellis (A '23) formerly commander, United States Naval Reserve, has been released from active duty. He served in several capacities and more recently as assistant inspector of naval material for the Western Electric Company and the Bell Telephone Laboratories, New York, N. Y. He was commissioned lieutenant commander in 1942 and promoted to commander in 1943.

Olav Maseng (M '25) major, Army of the United States, has been cited for the Bronze Star Medal for "the successful discharge of those responsibilities which resulted in the restoration of electric plants and lines and solid fuels redevelopment in France and Belgium, and enabled those governments, as far as military necessity permitted, to discharge their responsibilities." Before entering military service Major Maseng was affiliated with the Square D Company, Detroit, Mich.

F. C. Bates (A '41) formerly maintenance engineer, production and transmission department, Utah Power and Light Company, Salt Lake City, is now with the Westinghouse Electric Corporation as electrical engineer in the engineering and service department at San Francisco, Calif. From 1942 to 1945 Mr. Bates served as a civilian engineer in the engineering branch of the headquarters, Ninth Service Command, United States Army.

W. G. H. Finch (A '22, M '26) has resumed the presidency of Finch Telecommunications, Inc., Passaic and Clifton, N. J., after having been released from active duty as captain, United States Naval Reserve. He was born in Birmingham, England, and has been associated with Allis-Chalmers Manufacturing Company, Norwood, Ohio, Cleveland (Ohio) Electric Illuminating Company, and Royal Indemnity Company, New York, N. Y. He also served the International News Service, New York, N. Y., as radio engineer.

D. C. Jackson (A '87, HM '44) professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been awarded honorary membership in the American Society of Mechanical Engineers for leadership in education and consulting-engineering fields.

K. F. Bellows (A '30, M '38) formerly division engineer, system engineering department, Consolidated Edison Company, of New York, New York, N. Y., Inc., has joined McKinsey and Company management consultants, as a consultant in the firm's New York office.

A. J. Swank (M '43) assistant electrical engineer, has succeeded Mr. McKay as station construction engineer. Mr. Swank in 1919 became associated with the Pacific Gas and Electric Company. He has held the positions of construction foreman and construction superintendent.

E. L. Lotz (A '38, M '45) formerly research director, New Jersey Wood Finishing Company, Woodbridge, is now with the Owens-Corning Fiberglas Corporation, Toledo, Ohio.

E. R. Hoyle (A '20, M '37) formerly assistant to electrical engineer, Sinclair Refining Company, East Chicago, Ind., is now electrical engineer.

E. P. Nelson (A '27, M '45) since 1933 assistant electrical engineer, Electric Boat Company, Groton, Conn., is now consulting engineer, Elliott Company, Ridgway, Pa.

E. H. Aiken (A '29, M '37) formerly electrical engineer, Imperial (Calif.) Irrigation District, has joined the staff of the General Electric Company, Los Angeles, Calif.

G. A. Fowles (A '37) formerly manager, electric wire and cable insulating materials, has been made sales manager for Geon thermoplastics of the B. F. Goodrich Chemical Company, Cleveland, Ohio.

J. M. Livingston (A '30) formerly sales manager, Schweitzer and Conrad, Inc., Chicago, Ill., has opened his own electrical sales-engineering office in Chicago.

W. W. Parker (A '30, M '37) switchgear and control department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed regional engineer of the Rio de Janeiro (Brazil) office of the Westinghouse International Company.

Noel Pike (A '25, M '32) formerly superintendent of construction, Cia Impulsora de Empresas Electricas, Mexico, Federal District, Mexico, is now chief electrical engineer of the Imperial (Calif.) Irrigation District.

E. L. Harder (A '30, M '41) central-station engineer in the industry-engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has received the Order of Merit from his company.

V. T. Johnson (A '33) formerly of the research and records section, Los Angeles (Calif.) Bureau of Power and Light now is serving as chief of the operation division of the Rio de Janeiro (Brazil) Tramway, Light and Power Company's electric system.

C. R. Hanna (A '24, F '44) associate director of the research laboratories, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been awarded the degree of doctor of engineering by Purdue University, Lafayette, Ind.

A. L. Maillard (M '23) superintendent, power and distribution, Military Chemical Works, Pittsburgh, Kan., has been appointed managing director of the Electric League of Indianapolis, Ind.

D. S. Jacobus (A '03) retired from Babcock and Wilcox Company of New York, N. Y., recently was made an honorary member by the American Welding Society.

OBITUARY.....

Bryson Dexter Horton (A '14) retired president, Square D Company, Detroit, Mich., died December 14, 1945. He was born in Fenton, Mich., September 28, 1871, and received a bachelor-of-science degree from the University of Michigan in 1895. For the first four years of his career he was electrical engineer, Public Lighting Company, Detroit, and then for a year served as electrical engineer for the Detroit Copper Mining, Morenci, Ariz. Subsequently he became general manager of the Detroit Fuse and Manufacturing Company. During the Spanish-American War he served as chief electrician of the USS *Yosemite*. In 1903 he founded the Square D Company and remained its president until 1928, the year of his retirement. Mr. Horton served for four years as advisor to the Public Works Administration, State of Michigan. He was a member of the board of directors of the Rackham Engineering Foundation, a corporation with title to the $500,000 endowment created by Horace H. Rackham and Mary A. Rackham Fund for the benefit of the engineering professions and allied arts and sciences in the Detroit area. He was a member of the board of governors of the Horace H. Rackham school of graduate studies, University of Michigan, and an honorary member of the Engineering Society of Detroit. He is credited with inventing the arcless enclosed fuse and electric safety switches.

Norman Graves Reinicker (M '18) formerly vice-president and general manager, Pennsylvania Power and Light Company, Allentown, Pa., died January 13, 1946. Mr. Reinicker was born in Baltimore, Md., November 13, 1889, and was graduated from Cornell University (1911) with the degree of mechanical engineer. In 1911 he went to work in the research and test department of the Detroit (Mich.) Edison Company and subsequently became boiler room engineer and assistant chief engineer. Then he became assistant to the chief engineer of the New York (N. Y.) Edison Company. After a short period as power superintendent, Du Pont Engineering Company, Nashville, Tenn., Mr. Reinicker became affiliated in 1919 with the Lehigh Valley Light and Power Company, Allentown, one of the predecessors of the Pennsylvania Power and Light Company, as superintendent of operations. When a few years later the Pennsylvania Power and Light Company was organized Mr. Reinicker became its superintendent of operations and later was made general superintendent and general manager. He was named vice-president and general manager in 1935. He was a former president of the Pennsylvania Electric Association and the Lehigh Valley Engineers' Club.

W. P. MacDonald (M '43) general manager, British Columbia Power Commission, Vancouver, Canada, died November 30, 1945. Mr. MacDonald was born in Sherbrooke, Quebec, Canada, January 3, 1892, and in 1910 went to work for the Bell Telephone Company in that city. After two years he became associated with the Alberta Government Telephone Department, Edmonton, remaining in this assignment also two years. For a year he was identified with the Burnham Frith Electric Company, and in 1917 became foreman in the meter department of the City of Edmonton Light and Power Department. There he remained until 1928 when he was made district superintendent of the Canadian Utilities, Limited, Calgary, and in 1931 he became manager, Nanaimo-Duncan Utilities, Limited, Nanaimo, Vancouver, prior to the time that power company was taken over by the British Columbia Power Commission. More recently he had been general manager for the Vancouver Island of the British Columbia Power Commission. He was active in the Canadian Electrical Association and also took an active part in the welfare and civic work in Nanaimo.

Leo B. Hedges (A '28, M '42) chief load dispatcher, Bureau of Power and Light, City of Los Angeles, Calif., died November 30, 1945. Mr. Hedges was born February 7, 1888, in Bloomington, Ill., and studied at the University of Illinois and the University of Southern California. Early in his career he was an apprentice wireman in Bloomington. From 1913, when he took the position of assistant electrician for the Los Angeles Aqueduct, until his death, he served that city in various capacities. With the Bureau of Power and Light he was electric crane operator (1915–17); power plant operator (1917–22); load dispatcher (1922–31); assistant chief load dispatcher (1931–39); and chief load dispatcher. In that latter assignment he was in charge of the new dispatching headquarters containing many advanced facilities which was placed in service in 1941.

C. H. Van Slyck (A '03) prior to his retirement five years ago vice-president and treasurer, Watson-Flagg Engineering Company, New York, N. Y., died in December 1945. Mr. Van Slyck was born in Schenectady, N. Y., and after leaving high school, spent three years in the students' course of the General Electric Company both at Schenectady and at Lynn, Mass. He worked also in the commercial department of the company. Early in his career he was superintendent of equipment of the Coney Island and Brooklyn Railroad, Brooklyn, N. Y., and shortly thereafter became identified with the Watson-Flagg Engineering Company which he served as secretary and treasurer, treasurer, and then vice-president and treasurer, the position he held at the time of retirement.

Henry Rutherford Gabay (A '07, M '30) retired, New York (N. Y.) Telephone Company, died January 12, 1946. Mr. Gabay was born in New York, June 14, 1876, and was graduated from Cornell University (1897) with a mechanical engineering degree in electrical engineering. He began his association with the New York Telephone Company in 1898 and served as housetop engineer, underground engineer, construction engineer, and in 1910 was made division commercial engineer. Later he was appointed division plant engineer (1912), commercial engineer (1913) and general commercial engineer (1920). He retired in 1941 after giving his services for 43 years to the company. As general commercial engineer Mr. Gabay became one of the country's authorities on telephone rates.

Frederick Dewey Jackson (M '42) associate professor of electrical engineering, University of New Hampshire, Durham, died December 18, 1945. Professor Jackson was born May 30, 1898, at Royersford, Pa., and was graduated from Pennsylvania State College with a bachelor-of-science degree (1920) and an electrical-engineer degree (1939). From 1921 to 1923 he was an instructor in the electrical engineering

department of Cornell University, Ithaca, N. Y., and in the latter year became engineer in the radio engineering department of the General Electric Company, Schenectady, N. Y. In 1924 he took the position of instructor in the electrical engineering department of the University of New Hampshire and in 1927 was made assistant professor, and associate professor in 1939. In 1944 he left the university to serve the Bell Telephone Laboratories, Inc., New York, N. Y., as engineer in the transmission department. Late in 1945 he returned to the university.

Charles Langdon Perry (A '03) formerly electrical control devices designer, General Electric Company, Schenectady, N. Y., died November 20, 1945. Mr. Perry was born in Astoria, N. Y., July 19, 1875, and was graduated in electrical engineering, Columbia University in 1896. A few months after leaving college he joined the staff of the General Electric Company and was employed by that firm for his entire life. In the engineering department he served as designing engineer and later as electrical engineer. Subsequently he was made industrial control engineer and finally entered the electrical control devices design department.

MEMBERSHIP . . .

Recommended for Transfer

The board of examiners, at its meeting of January 17, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections of these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Taylor, A. H., chief consultant and co-ordinator, Naval Research Laboratory, Washington, D. C.
Terrell, C. F., vice-president, Puget Sound Power & Light Co., Seattle, Wash.
Watkins, S. S., elec. engr., Gibbs & Hill, Inc., New York, N. Y.
West, C. P., mgr., switchboard engg., Westinghouse Electric Corp., E. Pittsburgh, Pa.

4 to grade of Fellow

To Grade of Member

Armstrong, C. V., Bell & Gossett Co., Morton Grove, Ill.
Brooke, H. L., sales mgr., Pacific Electric Mfg. Corp., San Francisco, Calif.
Brooks, J. D., utilities adviser, Federal Public Housing Authority, Washington, D. C.
Burkhart, J. R., proposition design engr., General Electric Co., Pittsfield, Mass.
Byrd, H. L., managing engr., pr. circuit breaker div., General Electric Co., Philadelphia, Pa.
Clagett, W. H., elec. engr., U. S. Bureau of Reclamation, Dept. of Interior, Coulee Dam, Wash.
Clark, E. N., Comdr., U. S. Navy, Decommissioning Section, San Francisco, Calif.
Clements, V. O., application engr., Westinghouse Electric Corp., Houston, Texas.
Cleveland, L. F., assoc. prof., elec. engg., Northeastern University, Boston, Mass.
Cottony, H. V., National Bureau of Standards, Washington, D. C.
Diz, W. H., asst. engr., Potomac Electric Power Co., Washington, D. C.
Endicott, H. S., elec. engr., General Electric Co., Pittsfield, Mass.
Fluke, J. M., Comdr., USNR, Bureau of Ships, Navy Dept., Washington, D. C.
Frank, C. W., asst. chief engr., Automatic Electric Co., Chicago, Ill.
Gregg, W. E., Jr., asst. to gen. mgr., Monitor Controller Co., Baltimore, Md.
Hatch, W. H., engr., Public Service Co. of Northern Ill., Chicago, Ill.
Heibel, J. D., mgr., condenser div., Erie Resistor Corp., Erie, Pa.
Hellmann, K., elec. engr., Philadelphia Navy Yard, Philadelphia, Pa.
Janowitz, A. W., sales engr., General Electric Co., Dayton, Ohio.
Keith, A. H., elec. engr., Consolidated Vultee Aircraft Corp., San Diego, Calif.
Killian, S. C., chief engr., Delta Star Electric Co., Chicago, Ill.
Lippert, G. D., elec. engg. dept., American Gas & Electric Service Corp., New York, N. Y.
Lloyd, T. C., chief engr., Robbins & Myers, Inc., Springfield, Ohio.
Meldrim, E. T., supt. of substations, Pacific Gas & Electric Co., Oakland, Calif.
Overgaard, H., elec. squad leader, Ebasco Services, Inc., New York, N. Y.
Page, E. R., instructor, University of Oklahoma, Norman, Okla.
Peters, C. S., elec. engr., Rural Electrification Administration, St. Louis, Mo.
Rineer, W. B., engr., Army Service Forces, Air Technical Service Command, Wright Field, Dayton, Ohio.
Rudd, H. H., vice-pres., Railway & Industrial Engg. Co., Greensburg, Pa.
Salati, O. M., senior engr., Haseltine Electronics Corp., Little Neck, N. Y.
Shelton, E. E., instructor, elec. engg., Cooper Union, New York, N. Y.
Sitkin, A., elec. engr., Voorhees, Walker, Foley & Smith, New York, N. Y.
Stanley, W. M., asst. construction supt., Tennessee Valley Authority, Wilson Dam Branch, Sheffield, Ala.
Theriault, G. I. F., equip. engr., Frigidaire Div., General Motors Corp., Dayton, Ohio.
Wickham, W. H., engr., testing dept., Commonwealth Edison Co., Chicago, Ill.
Yost, J., director, Vose Memorial Laboratory, Great Neck, L. I., N. Y.

36 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before March 15, 1946, or May 15, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Colton, R. B., Maj. Gen., USA, Army Air Forces, Washington, D. C.

1 to grade of Fellow

To Grade of Member

Adams, R. T., The Ambos-Jones Co., Cleveland, Ohio
Anderson, R. B., The Grampian Electricity Supply Co., Perth, Scotland
Bartlett, G. S., Public Service Co. of Northern Illinois, Highbrook, Ill.
Bartlett, S. C., American Gas & Electric Service Corp., New York, N. Y.
Basil, A. S., United States Rubber Co., New York, N. Y.
Byrnes, T. F., Cutler Hammer, Inc., Milwaukee, Wis.
Cain, E. S., Scaife Co., Oakmont, Pa.
Callaham, P. R., Abbott Laboratories, North Chicago, Ill.
Carruth, J. A., Gulf States Utilities Co., Lake Charles, La.
Chambliss, L. M., The Commonwealth & Southern Corp., Birmingham, Ala.
Collier, D. F., Westinghouse Elec. Supply Co., Boston, Mass.
Cyphert, D. W., 11th Naval Dist. Public Works, San Diego, Calif.
Fairfield, R. M., British Insulated Callender's Cables, Ltd., London, England
Frederick, C. L., Cornell Aeronautical Lab., Buffalo, N. Y.
Fyfe, R., The Grampian Electricity Supply Co., Perth, Scotland
Garside, B. H., Britannic Electric Cable & Construction Co. Ltd., Iver, Buckinghamshire, England
Greene, R. R., Stockwell Transformer Corp., Akron, Ohio
Hale, S. G., Bell Telephone Labs., Inc., New York, N. Y.
Harper, W. E., Davis Transformer Co., Concord, N. H.
Heberlein, G. E., Railway & Industrial Engineering Co., Greensburg, Pa.
Heinlein, P. P., Jr., Lt. Col., U. S. Military Academy, West Point, N. Y.
Hilbert, E. W., N. Y. Telephone Co., New York, N. Y.
Hill, L. R., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Honnell, F. M., Lt. Col., Signal Corps, West Point, N. Y.
Kinghorn, J. H., American Gas & Electric Service Corp., New York, N. Y.
Kracpelien, H. Y., Ericsson Telephone Sales Corp., New York, N. Y.
Kreadorn, R. R., University of Texas, Austin, Tex.
Landmeier, E. W., Wadsworth Electric Mfg. Co., Inc., Covington, Ky.
Leiter, K. S., Capt., Signal Corps, AUS, Peoria, Ill.
Ma, G. C. K., Metropolitan-Vickers Elect. Co., Ltd., Manchester, England
McDaniel, G. H., American Gas & Electric Service Corp., New York, N. Y.
O'Connor, J. P., Westinghouse Elec. Corp., Boston, Mass.
Pulsford, J. A., Public Service Electric & Gas Co., Newark, N. J.
Rao, D. S., M. E. S., Hospital Town East, Bangalore, India
Richard, W. J., General Cable Corp., New York, N. Y.
Rose, H. A., Westinghouse Electric Corp., Seattle, Wash.
Schseichlin, W. (Re-election), Westinghouse Elec. Corp., East Pittsburgh, Pa.
Schramm, R. F., Arthur G. McKee Co., Cleveland, Ohio
Siler, A. E., North American Aviation, Inglewood, Calif.
Slack, R. C., American Gas & Elec. Serv. Corp., New York, N. Y.
Thoen, R., Farrel Birmingham Co. Inc., Buffalo, N. Y.
Thompson, W. W., Thompson Engineered Lighting Co., Boston, Mass.
Tsai, C-N, National Resources Comm., Washington, D. C.
Turner, E. M., Erie Resistor Corp., Erie, Pa.
Watkins, W. S., Ohio Rubber Co., Willoughby, Ohio
Westby, H. W., Tennessee Valley Authority, Knoxville, Tenn.
Williams, H. L., Burlington Electric Light Dept., Burlington, Vt.
Woodworth, C. O., Schockett Elec. Co., Denver, Colo.
Wright, J. T., Rural Electrification Administration, Madison, Wis.
Zeller, C. J., Consolidated Edison Co., New York, N. Y.

50 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Booth, C. E., Westcott & Mapes, New Haven, Conn.
Brandow, L. L., New York State Electric & Gas Corp., Binghamton, N. Y.
Clarkson, C. W., Jr., Corning Glass Works, Corning, N. Y.
Hall, H. W., Cambridge Elec. Light Co., Cambridge, Mass.
Horn, J. R., Boston Naval Shipyard, Cambridge, Mass.
Hunsicker, F. F., Westinghouse Electric Corp., Boston, Mass.
Hurley, R. J., United Illuminating Co., New Haven, Conn.
Ironside, D. S., Stromberg Carlson Tel. Co., Rochester, N. Y.
Jankowski, H., General Elec. Co., Schenectady, N. Y.
King, L. A., Jackson and Moreland, Boston, Mass.
Levitsky, F. J., Worcester Polytechnic Inst., Worcester, Mass.
Manzi, A. P., Manzi Electrical Co., Lawrence, Mass.
Murphy, M. D., United Illuminating Co., English Station, New Haven, Conn.
Ottalagana, J. S., Stromberg-Carlson Co., Rochester, N. Y.
Pickering, C. B., Jr., Allen-Bradley Co., Boston, Mass.
Quimby, R. B. (Re-election), General Electric Co., Schenectady, N. Y.
Smith, N. T., General Electric Co., Pittsfield, Mass.
Stellato, J. R., Dept. of Public Works, Albany, N. Y.
Tholstrup, H. L. (Re-election), International Business Machines Corp., Rochester, N. Y.
Webb, L. M., Hartford Electric Light Co., Hartford, Conn.
Wilder, W. D., Buffalo Niagara Electric Corp., Buffalo, N. Y.

2. Middle Eastern

Ballowe, J. C., Charleston Electrical Supply Co., Inc., Charleston, W. Va.
Barry, L. T., Electric Service Mfg. Co., Philadelphia, Pa.
Bartlett, D., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Bidle, C. P., Ohio Crankshaft Co., Cleveland, Ohio
Bindschadler, E., Westinghouse Electric Corp., East Pittsburgh, Pa.
Bodenstein, B. E., Brown Instrument Co., Philadelphia, Pa.
Campbell, R. E., Keystone Shipping Co., Philadelphia, Pa.
Crooker, P. R., Line Material Co. of Pennsylvania, East Stroudsburg, Pa.
Currens, C., Jr., Bethlehem Steel Co., Baltimore, Md.
Dickinson, W. E., Maj., Wright Field, Dayton, Ohio
Dotzon, C. E., Jr., American Tel. & Tel. Co., Dayton, Ohio
Edgell, R. E., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Fischer, G. H. (Re-election), Middle Dept. Association of Fire Underwriters, Philadelphia, Pa.
Forrest, E. P. (Re-election), General Electric Co., Philadelphia, Pa.
Furfari, F. A., Westinghouse Elec. Corp., Cleveland, Ohio
Grimm, W. L., Jr., The Johns Hopkins Univ., Baltimore, Md.

Grynkewich, N. E., General Electric Co., Baltimore, Md.

Hammerquist, R. C., United Engineers & Constructors, Inc., Philadelphia, Pa.

Harris, A. G., Bethlehem Steel Co., Baltimore, Md.

Hess, W. J., 302 Morrison Bldg., Charleston, W. Va.

Hull, R. E., Westinghouse Electric Corp., Pittsburgh, Pa.

Huseby, S. B., E. I. DuPont DeNemours & Co., Inc., Belle, W. Va.

Johnson, B. W., Kanawha Valley Power Co., Charleston, W. Va.

Kingsley, H. D., General Elec. Co., Baltimore, Md.

Lehmkuhl, H. F., Frigidaire Division of G.M.C., Dayton, Ohio

Leinberger, F. A., General Electric Co., Philadelphia, Pa.

Marsteller, R. Z., Philadelphia Electric Co., Norristown, Pa.

McCollin, J. C., Capt., British Army Staff, Washington, D. C.

Mikell, S. H., Edison Light and Power Co., York, Pa.

Mirsch, J. W., General Electric Co., Baltimore, Md.

Myers, F. E., National Cash Register Co., Dayton, Ohio

O'Leary, C. J., Western Electric Co., Baltimore, Md.

Ramey, R. S., Ens., USNR, Middletown, Ohio

Reed, F. J., Philadelphia Electric Co., Philadelphia, Pa.

Reese, F. D., Pennsylvania Telephone Corp., Erie, Pa.

Richards, A. T., Westinghouse Electric Corp., Sharon, Pa.

Rottman, W. J., The Hoover Co., North Canton, Ohio

Rundt, R. H., Westinghouse Electric Corp., East Pittsburgh, Pa.

Schulman, E. L., Westinghouse Electric Corp., East Pittsburgh, Pa.

Shoup, R. W., Insulation Manufacturers Corp., Cleveland, Ohio

Soos, S. W., Jr., Lake Shore Elect. Mfg. Corp., Cleveland, Ohio

Stafford, B. H., Naval Research Laboratory, Washington, D. C.

Stauffer, P. H., Westinghouse Electric Corp., Akron, Ohio

Stuffer, N., Westinghouse Electric Corp., Cleveland, Ohio

Tippy, G. F., General Elec. Co., Dayton, Ohio

Underhill, B. B., Penn. State College, State College, Pa.

Vidal, N. F., Pennsylvania Power Co., Sharon, Pa.

Warren, R. E., Westinghouse Elec. Corp., Toledo, Ohio

White, E. A., Naval Research Lab., Washington, D. C.

Wiatt, F. E. (re-election), Cincinnati Gas & Electric Co., Cincinnati, Ohio

3. New York City

Alpert, N., Republic Aviation Corp., Farmingdale, L. I., N. Y.

Arkus, H., Hazeltine Corp., Little Neck, L. I., N. Y.

Balacki, S. J., Newark Signal Corps Inspection Zone, Newark, N. J.

Barrett, E. M., Long Island Lighting Co., Mineola, N. Y.

Bergen, A. R., Lt., Sig. C., AUS, Ft. Monmouth, N. J.

Bierman, M., Underwriters' Laboratories, Inc., New York, N. Y.

Christ, G. J., N. Y. Telephone Co., Brooklyn, N. Y.

Clark, B., Electric Storage Battery Co., New York, N. Y.

Foote, C. L., Gibbs & Hill, Inc., New York, N. Y.

Goetz, D. F., Ens., USNR, Staten Island, N. Y.

Grisler, H. W., Public Service Electric & Gas Co., Newark, N. J.

Hutlof, E. W., Public Service Elec. & Gas Co., Newark, N. J.

Jamieco, D. S., U. S. Naval Shipyard, Brooklyn, N. Y.

Karlsbad, D. B., U. S. Rubber Co., New York, N. Y.

Lothe, R. N., Lt. Army Signal Corps, Fort Monmouth, N. J.

Mandels, A., 315 West 86th St., New York, N. Y.

Pope, C. A., General Cable Co., Perth Amboy, N. J.

Rich, F. N., 315 West 98th Street, New York, N. Y.

Sokol, W. J., The M. W. Kellogg Co., New York, N. Y.

Stack, J. B., Field Prod. Div., U. S. Naval Shipyard, New York, N. Y.

Sussman, H., Hazeltine Corp., Little Neck, N. Y.

Wang, S., National Resource Comm. of China, New York, N. Y.

Wiener, B. S., 1212 Newkirk Ave., Brooklyn, N. Y.

4. Southern

Albritton, L. E., Hq. Fourth Service Command, Atlanta, Ga.

Bishop, L., Tenn. Eastman Corp., CEW, Oak Ridge, Tenn.

Chaffee, M. H., Jr., Virginia Electric & Power Co., South Boston, Va.

Check, C. C., Carbide & Carbon Chemicals Corp., Oak Ridge, Tenn.

Cooper, R. J. (Re-election), Georgia Power Co., Atlanta, Ga.

Darden, T. N., General Electric Co., Atlanta, Ga.

Davenport, T. O., Tenn. Eastman Corp., CEW Oak Ridge, Tenn.

Dorr, W. F., U. S. Maritime Comm., c/o N. C. Shipbuilding Co., Wilmington, N. C.

Flournoy, L. C., Alabama Power Co., Birmingham, Ala.

Green, F. R., Green Electric Co., Columbia, S. C.

Helfrich, R. B., General Elec. Supply Co., Norfolk, Va.

Henley, R. D., Tenn. Eastman Corp., Oak Ridge, Tenn.

Hollins, F. G., Southern Bell Tel. & Tel. Co., New Orleans, La.

Jacobsen, W. E., Comstock & Bryant Companies, Knoxville, Tenn.

Kirkland, H. G., Florida Power Corp., St. Petersburg, Fla.

LeBlanc, R. E., III, Lt. (jg), U. S. Navy, New Orleans, La.

McGraw, L. A., General Elec. Co., Birmingham, Ala.

Molbert, J. J., Cities Service Refining Corporation, Lake Charles, La.

Roluft, F. M., John McNeese Junior College, Lake Charles, La.

Saunders, R. K., 66 Norwood Circle, Birmingham, Ala.

Shaver, E. E., North Carolina Shipbuilding (USMC), Wilmington, N. C.

Simmons, D. W., Southern Bell Tel. & Tel. Co., Greenville, Miss.

Smith, R. T., Tennessee Valley Authority, Chattanooga, Tenn.

Smull, M. P., The Commonwealth & Southern Corp., Birmingham, Ala.

Strassmeyer, A. H., Kellex Corp., Oak Ridge, Tenn.

Tribble, W. F., Duke Power Co., Charlotte, N. C.

Trischman, C. A., Virginia Electric & Power Co., South Boston, Va.

Tuck, D. R., Virginia Electric & Power Co., South Boston, Va.

Turner, W. C., Alabama Power Co., Birmingham, Ala.

Vickrey, H. H., The Commonwealth & Southern Corp., Birmingham, Ala.

Williams, N. F., The Commonwealth & Southern Corp., Birmingham, Ala.

Zara, F., Georgia Power Co., Atlanta, Ga.

5. Great Lakes

Balser, H. W., Automatic Electric Co., Chicago, Ill.

Bowman, L. J., A.C. Spark Plug, Flint, Mich.

Bracken, J. F., Commonwealth Edison Co., Chicago, Ill.

Brubaker, J. L., Western Electric Co., Chicago, Ill.

Cawson, W. F. (Re-election), Public Service Co. of No. Ill., Chicago, Ill.

Clark, F. S., The Milwaukee Elec. Ry. & Transport Co., Milwaukee, Wis.

Concha, D., Allis Chalmers Mfg. Co. (I.T.A.), West Allis, Wis.

Cress, W. M. (Re-election), Public Service Co. of No. Ill., Glencoe, Ill.

Detuno, R. J., Western Electric Co., Chicago, Ill.

Deuscher, K. E., Kuhlman Electric Co., Bay City, Mich.

Diefenbach, A. E., A.C. Spark Plug Div., Flint, Mich.

Fash, R. A., Aluminum Ore Co., E. St. Louis, Ill.

Gale, H. E., Western Electric Co., Inc., Chicago, Ill.

Gamble, M. E., P. R. Mallory & Co., Indianapolis, Ind.

Gassner, F., Bruce Cumming & Associates, Chicago, Ill.

Ghormley, R. K., Automatic Electric Co., Chicago, Ill.

Hall, R. C., Commonwealth Edison Co., Chicago, Ill.

Hammel, A. E., Allis Chalmers Manufacturing Co., Milwaukee, Wis.

Hauck, A. J., Surges Electric Co., Milwaukee, Wis.

Hoffman, J. R., Illinois Power Co., Belleville, Ill.

Horn, A. S., General Electric Co., Chicago, Ill.

Jackson, C. E., Paranite Wire & Cable Corp., Jonesboro, Ind.

Jacobson, L., G-M Laboratories, Inc., Chicago, Ill.

Kelley, H. E., Dow Chemical Co., Midland, Mich.

Kollingwith, H. F., Kuhlman Electric Co., Bay City, Mich.

Lane, M. G., Iowa Ordnance Plant, Burlington, Iowa

Maddox, R. D., Belden Manufacturing Co., Richmond, Ind.

Meece, H. C., Aluminum Company of America, Chicago, Ill.

Miller, L. H., Jr., Commonwealth Edison Co., Chicago, Ill.

Muir, D. W., Automatic Electric Co., Chicago, Ill.

Parker, E., General Motors Corp., Detroit, Mich.

Rose, W. H., Public Service Co. of Nor. Ill., Chicago, Ill.

Standifird, G. B., Sargent and Lundy Engineers, Chicago, Ill.

Swierczak, P. C., General Motors, Delco Remy Div., Anderson, Ind.

Swigart, H. E., Western Electric, Chicago, Ill.

Tanyolac, N. N., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Weed, L. A., AC Spark Plug Div., GMC, Flint, Mich.

Weyrauch, J. R., Public Service Co. of Nor. Ill., Chicago, Ill.

Wheeler, R. M., AC Spark Plug Div., GMC, Flint, Mich.

Wilson, T. J., Minneapolis Honeywell Regulator Co., Minneapolis, Minn.

6. North Central

Brand, O. H., Nebraska Public Power System, Omaha, Nebr.

Hankins, R. E., M.S.T. & T. Co., Denver, Colo.

Roadhouse, C. S., Nebraska Power Co., Omaha, Nebr.

7. South West

Barrett, J. H., 2635 Park St., Beaumont, Tex.

Bryant, J. H., P. O. Box 151, Clyde, Tex.

Clyne, W. E., Federal Communications Commission Beaumont, Tex.

Cottom, M. C., University of Kansas, Lawrence, Kan.

Dyer, R. D., Tuco Plant, Abernathy, Tex.

Farnsworth, B. W., Lt., Signal Corps, Salina, Kan.

Hasty, C. M., Lower Colorado River Authority, Austin, Tex.

Hercher, W. D., Arkansas Power & Light Co., Pine Bluff, Ark.

Ingraham, C. W., Sangamo Elec. Co. of Springfield, Ill., Forth Worth, Tex.

Large, R. E., Southwestern Bell Tel. Co., Tulsa, Okla.

Larson, C. A. (Re-election), St. Joseph Light and Power Co., St. Joseph, Mo.

Lebow, B. I., Kansas Gas & Electric Co., Wichita, Kan.

Miller, A. G., 426 Dwight Bldg., Kansas City, Mo.

Price, R. T., Southwestern Public Service Co., Amarillo, Tex.

Sather, R. O., Maj., A.A.F., Roswell, N. Mex.

Shawver, E. F., Southwestern Bell Telephone Co., Houston, Tex.

Spence, W., Gulf States Utilities Co., Beaumont, Tex.

Walker, L. B. (Re-election), Lower Colorado River Authority, Austin, Tex.

Wheeler, D. J., Texas Electric Service Co., Fort Worth, Tex.

Woolsey, L. S., Marion L. Crist & Associates, Engr., Little Rock, Ark.

Yelderman, G. R., General Electric Co., Dallas, Tex.

Young, V. R., Graybar Electric Co., Dallas, Tex.

8. Pacific

Benson, A. R., North American Aviation, Inc., Inglewood, Calif.

Burns, A. E., The Pacific Tel. & Tel. Co., San Francisco, Calif.

Caton, D. H., San Diego Gas and Electric Co., San Diego, Calif.

Clark, A. G., U. S. Post Office, Los Angeles, Calif.

Daly, G. M., 1140 E St., Eureka, Calif.

Dehrer, L. G., U. S. Navy, Mare Island, Vallejo, Calif.

Delano, F. X., E.M.2/c, U. S. Naval Training Center, San Diego, Calif.

Denholm, D. A., Southern Calif. Edison Co., Ltd., Alhambra, Calif.

Eaton, R. A., San Francisco Naval Ship Yard, San Francisco, Calif.

Engel, R. L., Allis-Chalmers Mfg. Co., Los Angeles, Calif.

Fitch, H. R., War Department, McClellan Field, Calif.

Grauer, C. T., Univ. of Calif., Berkeley, Calif.

Jessen, O. C., Department of Water and Power, Los Angeles, Calif.

Lowerison, C., Southern Calif. Edison Co., Los Angeles, Calif.

Oddell, F. C. F. Braun & Co., Alhambra, Calif.

Overholser, P. H., So. Calif. Edison Co., Los Angeles, Calif.

Potter, W. T., Jr., So. Calif. Telephone Co., Los Angeles, Calif.

Sainsbury, T. R., San Francisco Naval Shipyard, San Francisco, Calif.

Schomberg, H. J., California Electric Power Co., Riverside, Calif.

Smith, C. L., Pacific Gas and Electric Co., Fresno, Calif.

Swift, F. T., Southern Calif. Telephone Co., Los Angeles, Calif.

Tarbell, R. J., San Diego Gas and Electric Co., San Diego, Calif.

Wood, C. L., Kaiser Co., Inc., Richmond, Calif.

9. North West

Eggren, J. E., Utah Power & Light Co., Salt Lake City, Utah

Irwin, R. A., Lt., USNR, U.S. Naval Shipyard, Bremerton, Wash.

Moses, D., GE Supply Corp., Spokane, Wash.

Parsons, C. B. (Re-election), C. B. Parsons & Co., Seattle, Wash.

Perason, J. S., Utah Copper Co., Magna, Utah

Reese, W. F., Utah Copper Co., Arthur, Utah

Rose, N. L., General Electric Co., Tacoma, Wash.

Thomas, K. W., Westinghouse Elec. Corp., Spokane, Wash.

10. Canada

Edson, R. E., Canadian General Electric Co., Montreal, Que., Can.

Morris, R. M., Nat. Research Council, Ottawa, Ont., Canada

Elsewhere

Adams, G. F., Messrs. Coverly Kendall, Lincolnshire, England

Ahmed, M., P.W.D., Anantagiri, Vikarabad, India

David, J. C., Central P.W.D., Simla, India

Miao, S. Y., Chungking Power Co., Chungking, China

Mukerjee, M. N., British Insulated Callender's Cables Ltd., Fort Bombay, India

Roden, A. H., General Electric Co., Ltd., Birmingham, England

Streuli, W. R. (Re-election), Brown Boveri & Co. Ltd., Baden, Switzerland

Total to grade of Associate

United States and Canada, 224

Elsewhere, 7

OF CURRENT INTEREST

Handbooks Issued on Wiring Design

Rudiments of the planning of electric wiring for the farmstead and for the single-family dwelling are covered in two pamphlets recently published and now available for distribution by the Industry Committee on Interior Wiring Design, Room 2650, 420 Lexington Avenue, New York 17, N. Y. The committee personnel includes representatives of appropriate branches of electrical industry. The project as a whole has been sponsored jointly by: American Institute of Electrical Engineers, American Home Lighting Institute, American Society of Agricultural Engineers, Edison Electric Institute, Illuminating Engineering Society, International Association of Electrical Inspectors, National Electrical Contractors Association, National Electrical Manufacturers Association, National Electrical Wholesalers Association, and Radio Manufacturers Association.

The purpose of these pamphlets is definitely not to explain how to install electric wiring, but rather to provide a comprehensive and standardized guide to the planning of electric wiring. According to the committee, it is the purpose of these pamphlets "to establish a list of recommendations, compliance with which will result in an efficient and convenient wiring system giving adequacy for present and anticipated future needs," and to "help avoid electrical obsolescence."

"Handbook of Farmstead Wiring Design" is a 54-page pamphlet specifically intended to help agricultural colleges, electric utilities, architects, engineers, builders, electrical contractors, lending institutions, sellers, buyers, and the farmer. It is illustrated generously with sketches and diagrams. Under the heading "Interior Wiring Design of Farmstead Buildings," the 16 sections cover such topics as definitions; branch and feeder circuits; dairy, poultry, beef cattle, horse, sheep, and hog structures; field, fruit, and vegetable crops; farm shops; water supply; farm residence; service equipment. Under the heading "Electrical Distribution (Exterior) for Farmstead Buildings" the seven sections include planning and definitions; pole, outdoor, and indoor metering; exterior lighting; tables and reference data. Price, 40 cents per single copy.

"Handbook of Residential Wiring Design" for single-family dwellings is a 26-page pamphlet specifically "designed to be of help to architects, engineers, builders, electrical contractors, lending institutions, sellers, buyers, and home owners." The pamphlet is illustrated generously with charts and layout diagrams. In addition to giving electrical symbols, general requirements, definitions, and a tabular summary of required outlets, the subject matter covers specific outlet requirements for all the various types of rooms; feeder and branch circuit requirements, and special requirements to accommodate signal and communication, radio and television, and telephone.

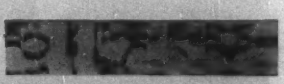
The committee now is turning its attention toward the preparation of similar handbooks for multifamily dwellings, and for commercial and industrial buildings.

"Visible Speech" Experiments by Bell Telephone Laboratories

A device which transforms sounds into patterns on a screen so that observers can see at a glance the character of the sound, whether it be speech, music, or noise, was demonstrated recently by Bell Telephone Laboratories, Inc., New York, N. Y.

The apparatus makes use of the fact that speech is defined fully by three quantities—pitch, loudness, and time. Sound at any instant can be analyzed by separating it into a suitable number of pitch groups, and measuring the intensity in each group. When this separating and measuring process is continuous, and the results are exhibited on a moving screen, patterns are formed which to a trained eye reveal not only the words spoken, but also the dialect of the speaker.

It is expected that this experiment in



The sound of "Electrical Engineering" made visible at Bell Telephone Laboratories

"visible speech" eventually will equip the deaf person with a vocabulary of patterns as extensive as he is willing to acquire. But more than this it will convey factors of timing and emphasis which carry much of the emotional content of speech.

Two types of visible-speech instruments were shown at the demonstration. One, which made permanent records, consists of a loop of magnetic tape on which the sound was recorded by the usual technique. This loop was driven through the reproducer at the same rate as a paper-covered drum was rotated. The tape was played back repeatedly and a variable filter was tuned to a different pitch for each repetition. These filters separated out the sounds of various pitches and the intensity of the filtered current controlled the blackening of successive strips around the drum. Another instrument presents a running portrayal of speech. In this the output of each of several filters is brought to one of a series of glow lamps in a vertical row. Passing through the field of light from the row of lamps is an endless belt coated with phosphorescent material. As each lamp brightens and dims, a stream of light trails along the belt and so paints the patterns of visible speech. Passing out of sight, the pattern is erased by infrared illumination to leave a clean surface for new patterns. A variant of this method is one which employs a special form of cathode-ray tube. The beam of electrons sweeps vertically, while the sensitized surface revolves.

The Bell Laboratories states that the new apparatus is still in its early stage of development and in addition, any prospective users, of course, would require considerable instruction.

Mobile Radiotelephone Service Trial by Bell System

Plans for service trials of mobile radiotelephone service along three intercity highway routes totaling nearly 1,000 miles were announced recently by the Bell Telephone Laboratories, Inc., New York, N. Y. The routes are those between Chicago and St. Louis, via Ottawa, Peoria, and Springfield, Ill., between New York, Albany, and Buffalo, and between New York and Boston. Transmitting and receiving stations required to provide the two-way voice communication service will be located along the routes.

Calls will be handled by mobile-service telephone operators. The conversations will travel part of the way by telephone wire and part by radio. The occupant of a mobile unit will be able to originate calls merely by picking up his telephone, listening to make sure the circuit is not in use, and pushing the "talk" button. This will signal the mobile service operator and she will "come in on the line," take the call, and put it through in normal fashion.

Plans for the system's mobile radiotelephone service on intercity routes are extensions of plans announced previously for urban mobile service. Progress already has been made in the program for establishing radiotelephone stations in certain cities to provide local service to vehicles, including trucks, cars, and boats within or around those localities.

Applications for authorization to establish the first stations to serve the Chicago–St. Louis route already have been filed with the Federal Communications Commission by the Illinois Bell Telephone Company. Operation of the new service will not begin until several months after the Commission authorizes construction.

Radio Relay System Between Chicago and Milwaukee

A series of microwave radio-relay stations designed to handle television, sound radio programs, or long distance telephone calls, is to be constructed between Chicago, Ill., and Milwaukee, Wis., according to a recent announcement of the American Telephone and Telegraph Company. The long-lines department of the company filed applications December 11, 1945, with the Federal Communications Commission for authority to build and operate this super-high-frequency radio relay system on an experimental basis. The cost is estimated at $500,000.

The terminals for the system will be at the Illinois Bell Telephone Company long-distance center in Chicago and at the Wisconsin Telephone Company's toll building in Milwaukee. There will be three radio repeater stations along the way, about 25 miles apart—one near Barrington, Ill., another near Wilmot, Wis., and the third in the vicinity of Prospect, Wis. Along this particular route the terrain is fairly level, so that station antenna towers about 12 feet in height will insure sufficient clearance for the straight-traveling microwaves. A building will be erected at the foot of each tower to house the power and other equipment needed.

Cash Prizes for Papers on Welding. Cash prizes totaling $2,000 will be awarded in 1946 by the Resistance Welder Manufacturers' Association, Cleveland, Ohio, for outstanding papers dealing with resistance welding subjects. The contest is open to anyone, without restriction, from the United States and its possessions and Canada, and to any member of the American Welding Society. Awards will be made at the 1946 fall meeting of the American Welding Society.

OTHER SOCIETIES

Radio Pioneers Hold Dinner

The radio pioneers' dinner of the New York section of the Institute of Radio Engineers was held in New York, N. Y., November 8, 1945, with more than 800 members and guests present. A brief historical note on the founding of the Institute of Radio Engineers in 1912 through merging the Wireless Institute of New York and the Society of Wireless Telegraph Engineers of Boston, Mass., was given by John V. L. Hogan (A '11, M '24). He pointed out that many of the reasons given to encourage the establishment of the Wireless Institute are still pertinent and as evidence quoted "radio will be developed faster if those engaged in it will work together more" which was contained in a letter written in 1909 by R. H. Marriott (A '06, F '26) to some 200 persons who, it was thought, might be interested in setting up a radio society.

Louis G. Pacent (M '18, F '30) president, Pacent Engineering Corporation, New York, served as chairman of the committee responsible for the dinner, and W. L. Everitt (A '25, F '36) president of the Institute of Radio Engineers, was master of ceremonies.

Chicago Show and Conference. "Production for Profit" will be the theme of the Chicago (Ill.) Production Show to be staged March 20–22, 1946, at the Stevens Hotel by the Chicago Technical Societies Council representing 46 scientific, engineering, and technological societies. The results of wartime advances in production tools, materials, handling devices, control instruments, and factory equipment in general will be on display for the community whose "Production for Victory" now yields to "Production for Profit." Manufacturers desiring information should get in touch with Paul A. Jenkins, execu-

"Compiling Industrial Injury Rates." The completion of a new American Standard on the method of compiling industrial injury rates has been announced by the American Standards Association, New York, N. Y. This code provides a practical basis for recording and measuring industrial injury experience. In order that the resulting records may have a uniform experience basis covering the entire country, the provisions are independent of state and Federal requirements for reporting injuries for workmen's compensation and of rulings on disability by workmen's compensation agencies. To facilitate interpretations of the rulings in this Standard provisions have been made for an interpretations committee so that uniform handling of questionable cases may be used.

INDUSTRY

Carrier Phones on REA Lines. Test installations of carrier telephone equipment have been made jointly by the Southwestern Bell Telephone Company, St. Louis, Mo., and the Rural Electrification Administration on the power lines of the Craighead Electric Co-operative Corporation, Jonesboro, Ark. In the new system, speech is transmitted by means of a carrier wave of radio-frequency. Appropriate transmitting and receiving equipment is installed at the switchboard and at the subscriber's end of the line. Dial instrument is used.

A 28-kw magnet designed and built at Westinghouse Research Laboratories is expected to develop a maximum field of 40,000 gausses between the pole pieces spaced one-half inch apart and attracted to each other with a pull of two tons. Positioned between the magnet pole pieces is a magnetic field measuring device called a generating flux meter by its designer. A constant-speed motor turns a small coil in the field to be measured. In this picture the position of the flux meter is being adjusted between the pole pieces.

tive secretary, Chicago Technical Societies Council, 53 West Jackson Boulevard, Chicago.

Canadian Electrical Manufacturers Meet. The first annual meeting of the Canadian Electrical Manufacturers Association was held at Niagara Falls, N. Y., October 24–25, 1945, with an attendance of more than 200. M. P. Murphy, vice-president, Amalgamated Electric Corporation, Limited, was chosen the new president to succeed A. B. Cooper (F '33), president, Ferranti Electric Limited. Vice-presidents elected were the following: A. S. McCordick (M '30), vice-president, Moloney Electric Company of Canada, Limited; J. S. Keenan, manager, supply department, Canadian General Electric Company, Limited; and L. F. A. Mitchell, manager of sales, Canadian Westinghouse Company, Limited.

New Officers of AIME Elected

The American Institute of Mining and Metallurgical Engineers has elected the following officers for the year 1946: president, L. S. Cates, president of Phelps Dodge Corporation, New York, N. Y.; vice-presidents and directors, H. J. Brown, consulting engineer, West Newton, Mass., and E. V. Daveler, vice-president of American Zinc, Lead and Smelting Company, New York. Six other directors of the AIME were elected also by letter ballot of members.

Future Meetings of Other Societies

American Association for the Advancement of Science. March 27–29, 1946, St. Louis, Mo.

American Chemical Society. National Chemical Exposition. September 10–14, 1946, Chicago, Ill.

American Society for Testing Materials. Forty-ninth annual meeting. June 24–28, 1946, Buffalo, N. Y.

American Society of Tool Engineers. Exposition. April 8–12, 1946, Cleveland, Ohio.

Illuminating Engineering Society. National convention. September 18–21, 1946, Quebec, Quebec, Canada.

Instrument Society of America. Exhibit and conference. September 16–20, 1946, Pittsburgh, Pa.

National Association of Corrosion Engineers. Annual meeting and convention. May 7–9, 1946, Kansas City, Mo.

National Electrical Manufacturers Association. First international lighting exposition. April 25–30, 1946, Chicago, Ill.

Pennsylvania Electric Association. Spring meeting. May 28–29, 1946, Harrisburg, Pa.

Radio Manufacturers Association. Trade show. May 13–16, 1946, Chicago, Ill.

Society of Plastics Industry. First national plastics exposition. April 22–27, 1946, New York, N. Y.

Midwest Power Conference in Chicago

After a year's lapse due to the war, the Midwest Power Conference under the sponsorship of Illinois Institute of Technology will be held at the Palmer House, Chicago, Ill., April 3–5, 1946. Cooperating with the Illinois Institute of Technology in the sponsorship of the conference are nine midwestern colleges and universities and several engineering societies, among the latter the AIEE Chicago Section.

Preliminary plans include a session on the gas turbine and papers on industrial power plants, central-station practice, insulation problems on power systems, and recent electrical developments.

S. E. Winston, recently appointed director of the evening division at Illinois Institute of Technology, is director of the conference. Assisting him as conference secretary will be C. A. Nash (A '12) associate professor of electrical engineering at Illinois Institute.

ASCE Officers Elected for 1946

W. W. Horner, St. Louis (Mo.) consulting engineer, has been elected president of the American Society of Civil Engineers for 1946. Vice-presidents elected are: Arthur W. Harrington, district engineer, United States Geological Survey, Albany, N. Y., and J. T. L. McNew, vice-president for engineering, Agricultural and Mechanical College of Texas, College Station. Both the vice-presidents are past directors of the society.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Name Suggested for Insulated Conductor

To the Editor:

In Tracy D. Waring's letter, which appeared in the October issue of *Electrical Engineering*, page 381, the suggestion is made that the word "icon" should be adopted to apply to an insulated conductor.

Unfortunately this word has already been used for an entirely different purpose. An icon is "an image or representation" of a saint or divinity, for example, and is so defined in Webster's dictionary, as well as in other languages.

Sorry to be an iconoclast, Mr. Waring, but won't you try again?

PAUL MacGAHAN (A'02, F '42)
(Consulting electrical engineer, Woodstock, N. Y.)

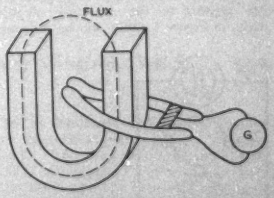
Electrical Essays for Recreation

To the Editor:

"No student would have any difficulty in recognizing what is wrong if our schools would cease to explain the law of electromagnetic induction by having a conductor 'cut' magnetic lines, but would adhere strictly to the fundamental concept that a voltage is induced when the flux associated with a loop is changing," writes Walter Richter in a letter to the editor (*EE, Oct '45, p. 387*).

Mr. Richter's plea for abandonment of the "cutting of-lines-of-force" theory of electromagnetic induction brings to mind some interesting electrical paradoxes presented for discussion by Carl Hering, AIEE president in 1901, more than 30 years ago. As I remember it, he described one of his experiments as follows:

Two metal springs are mounted on an insulating block around one leg of a horseshoe magnet with the outer ends of the springs connected to a galvanometer as shown in Figure 1.



When the springs are pulled to the right a closed loop is maintained as the ends of the springs slide over the leg of the horseshoe magnet. If the springs are pulled far enough to become free of the magnet, the flux within the closed loop will drop to zero, and yet no deflection would appear on the galvanometer, indicating that no voltage has been induced.

In this case there is a sudden change of flux interlinked with a closed loop, but there is no cutting of flux by a conductor

and there is no voltage induced. Doctor Hering, therefore, pleaded for a modification of Maxwell's law $e = N\frac{d\phi}{dt}$ so as to include actual cutting of flux in some way—in other words, just the opposite of the Richter recommendation.

Incidentally, correct reasoning from "cutting-of-flux" theory would have avoided the erroneous conclusion in the Richter illustration. The question is, "what kind of voltage is induced in the winding of an alternator when the field is excited with alternating current varying synchronously with the speed of the alternator?" The single-phase alternating field can be resolved into two components revolving in opposite directions. The velocity of the backwardly rotating field is neutralized by the mechanical rotation, becomes stationary in space, and induces no voltage. The velocity of the forwardly rotating field is added to the mechanical rotation and the resultant will induce a voltage of double frequency in the alternator winding. It was a misapplication of the "cutting-of-flux" theory which led to an erroneous deduction.

K. L. HANSEN (F '34)

(Consulting electrical engineer, Milwaukee, Wis.)

Glow Tube Motor Monitor

To the Editor:

The "negative-glow lamp," or glow lamp as it is called more frequently, can be used conveniently as a general purpose d-c motor monitoring instrument. Ferree[1] discussed characteristics and applications of this type of lamp, but did not present this interesting and useful application.

The glow lamp, when properly connected, will indicate direction of armature rotation, approximate speed of rotation, blocked armature conditions, and uneven running. The simplest application is that of a rotation direction indicator for a d-c motor. Figure 1 illustrates how the lamp should be connected for this purpose. D-c motor rotation reversal normally is accomplished by reversing the polarity of the voltage applied to the armature. Accordingly, in Figure 1 either one or the other

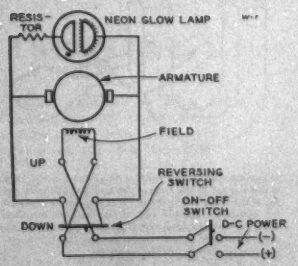


Figure 1. Method to indicate direction of d-c motor rotation

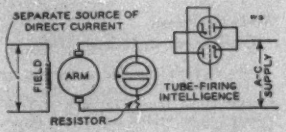


Figure 2. Back-to-back thyratron connection for motor reversing to show direction of rotation

Figure 3. Controller to position arc electrodes

Lamp indicates direction of movable electrode

electrode will glow, the glow emanating from the negative electrode, or cathode, as explained by Ferree, when the armature voltage is applied. The glowing electrode is thus an indication of the armature voltage polarity and consequently the direction of armature rotation. This information in turn is translated readily into motion specified as "right" or "left," "up–down" or "in–out" in some system operated by the motor. As shown in Figure 1, the right-hand electrode will glow if the reversing switch is in the "down" position.

In many electronically controlled d-c motor applications, the motor is operated by thyratrons connected "back to back" as illustrated in Figure 2, with control grid intelligence determining which thyratron fires, for selection of rotation direction. A glow tube connected as shown will indicate rotation direction as previously described, by either one or the other electrode glowing. In case of control grid failure resulting in both thyratrons firing at one time, the glow tube will signal this undesirable situation by both electrodes glowing brightly. If only one tube is firing, as desired, but the armature is blocked, then the appropriate electrode will glow brightly as usual, but the other electrode, instead of being dark, will glow faintly. This is because the blocked rotor represents an inductive load, and the half-wave pulse of current produces a high reverse voltage "kick" as the applied alternating voltage reverses in polarity and forces the current to zero.

When series resistance is used to control armature speed, then the intensity of the glow in the glow tube will be a fairly good qualitative indication of speed, if the lamp is connected directly across the armature. The greater the speed, the brighter will be the glow. If the rotor is blocked, or the speed drops below a value corresponding to armature voltage being equal to glow voltage, the tube will not fire. If speed is controlled by phase shift of the grid voltage of the tubes (Figure 2), the intensity of glow again will give an indication of speed. This control will produce glow tube indications down to lower speeds than those available with rheostatic control, because the instantaneous voltage across the armature, even when the tubes are "phased back" for slow speed, may be enough to fire the glow tube for a short portion of the cycle.

A pulsating load, with corresponding hunting of the motor, will be characterized by a flicker in the glow tube when rheostatic speed control is used, or when a poorly regulated power supply is employed with a "back to back" electron tube connection.

Figure 3 shows a neon glow lamp, used as a d-c motor monitor, mounted in the panel face of an electronic controller that operates positioning motors for electrodes in arc apparatus. The lamp indicates whether the electrode rods are moving apart or together, corresponding to up–down motion of the lower electrode rod. The lamp also indicates the lower rod reaching the bottom of its travel by the upper electrode glowing faintly. In normal operation the controller is mounted in a large operating panel board so that only the indicating lamps are visible.

REFERENCE

1. Some Characteristics and Applications of Negative-Glow Lamp, H. M. Ferree. AIEE *Transactions*, volume 60, 1941, January section, pages 9–11.

VICTOR WOUK (A '43)

(Westinghouse Electric Corporation, East Pittsburgh, Pa., now with North American Philips Company, Dobbs Ferry, N. Y.)

25th Anniversary of Radiobroadcasting

To the Editor:

I think you missed a point of interest in not identifying the announcer of KDKA in the picture on page 366 of the October 1945 issue of *Electrical Engineering*. He is Noah C. Pearcy (F '43) divisional engineer, Public Utility Engineering and Service Corporation, Chicago, Ill.

At the time of that picture he was taking a postgraduate course under B. G. Lamme with Westinghouse Electric and Manufacturing Company and announcing for KDKA in his spare time, announcing being a spare-time job in those days. The picture in the magazine is poor and no one without the necessary background would be able to identify him. I have letterheads on which this picture was used and in which the features are much plainer.

Noah and I were high-school mates and

later roommates at Gary, Ind., where we both were benchboard operators for the power plant of the United States Steel Company. We were "ham" operators in 1911 using spark-coil transmitters and electrolytic detectors. Later we built a vacuum-tube receiver and got music from Doctor Conrad's station at Gary in 1920.

I believe that Noah's one-leg stand in the picture was the result of his running over an automobile on the way to the studio, trying to get there in time to make a "scheduled broadcast." He was quite bruised but like a good trooper, his motto was, "the show must go on."

HARRY PEET, JR. (A '27)

(President, Kentucky Edison Company, Stanton, Ky.)

Impedances of Synchronous Machines

To the Editor:

A number of papers have been presented recently on the impedances of synchronous machines, principally along the lines of refinements in theory and methods of measurement. Useful as such efforts may be, it is more in order probably to re-survey the field of usefulness for such constants, principally the subtransient and transient, and to some extent the synchronous reactances.

The AIEE committee on synchronous machines has issued one report[1] and a revision[2] which constitute a beginning in the setting up of utilization Standards. There seems to be some tendency, which the committee probably does not share, to regard those standards as complete and final. The writer wishes to make some specific objections to statements about those Standards, but first to sketch a survey of the whole field.

Power system computations in which impedances of synchronous machines are used fall into three general groups:

1. The stress group. This includes computations of magnetic stresses on busses and other current carrying gear, interrupting duty of breakers (particularly the higher speed types), and the requirements for fuses and protector tubes, including the d-c components of current to be interrupted.

2. The relaying group.

3. The loading group, including stability under disturbances.

The demarkations between groups are not definite, as high-speed relays may be akin to fuses. Similarly, transient stability cannot neglect relays and conversely.

When Messrs. Hanna, Travers, Wagner, Woodrow, and Skeats published their paper, "System Short Circuit Currents,"[3] the writer contributed a discussion[4] relating to short-circuit currents as they affect relays. As the title of the paper was general this discussion was not out of order, but it may not have been too appropriate, as the original paper, like the standards which grew out of it, relates primarily to the stress group. Actually there is no particular reason for going from stress figures to relay figures, except that the stress standards are the first in the field, and some may consider the subject to be closed thereby.

The writer's specific objections as raised in the discussion were: The paper took no account of certain (rather rare) transient phenomena, and was of no help in determining current values appreciably after the start of the fault. In regard to the latter, the present writer recommended the use of the internal voltage method when that amount of precision can be justified, otherwise, to use transient reactance and voltage behind it.

The committee on Standards took cognizance of relays, other than high-speed, by recommending the use of transient reactance with unit voltage behind it, and omitted mention of saturation effects. The writer's own technique is to use transient or subtransient reactances on a d-c calculating desk, with a loaded network. That is, prior to the fault the net reactive load on each bus is represented by a drain through a load resistor. The appropriate average machine internal voltage (1.19 for system maximum and transient reactances) is applied. The writer does not suggest this as a Standard, but does believe that short-circuit current problems, as related to relays, are worth discussion and possibly standardization apart from stress current figures.

The writer believes that the AIEE report,[1] as revised,[2] is quite a large and helpful step, particularly as regards the tabulations it includes, but wishes to offer objections to some of the statements in the text. We read as follows:

The 3-phase short-circuit current is E/X_1. The line-to-line short-circuit current is $\sqrt{3}E/(X_1+X_2)$. Since X_2 is usually equal to or greater than X_1, this current seldom exceeds 86 per cent of the 3-phase short-circuit current, and consequently, for line-to-line faults the 3-phase fault-current value is generally satisfactory.

Some qualification besides the word "generally" in the afore-mentioned explanation should be used. *Generally*, it is true, but with respect to currents some time after the fault, there is much less decrement for phase-to-phase faults than for three phase, so that after an interval the phase-to-phase fault-current value may exceed the value for three phase at the same interval. If not a total but a branch current is in question, it may even exceed the initial 3-phase value for that branch.

We also read:

The line-to-ground short-circuit current is $3E/(X_1+X_2+X_0)$. Since usually X_2 is equal approximately to X_1 (using the subtransient value for X_1), this expression is often shortened to $3E/(2X_1+X_0)$. In practical cases regardless of the value of X_2, this last expression is satisfactory for determining the current in a double-line-to-ground fault.

This last sentence tends to give a definitely wrong impression, even though it may be true in many cases. It, with the previous sentence, tends to indicate that the relation of X_2 to X_1 is the important factor. Actually, however, the equivalent setup calls for paralleling X_2 with X_0 in series with X_1, and applying E to the combination, to obtain the sequence components from which phase conductor currents and ground currents can be derived. Therefore, the relation (in magnitude and phase angle) of X_2 with respect to X_0, determines whether the ground current for a double fault to ground is more or less than for a single line to ground fault. With impedance grounded neutrals, the double fault may give much less ground current than for a single line fault, but if the neutrals are grounded solidly and the fault is located so that the resultant X_0 is low, the ground current may exceed considerably that indicated. A recommendation in a Standard should not close the door to these possible exceptions.

It is necessary at this point to draw a distinction, which the Standards do not do, between the currents in the "hot" or phase equipment and those in neutral connections and gear, or those in grounding equipment. For double faults to ground, the ground current is made up of components from two phase leads, giving entirely different stresses to gear in the ground or neutral path.

In the second paragraph under "Procedure" it is said that either E/X_1 or $3E/(2X_1+X_0)$ will give "the highest value of rms symmetrical current for any type of fault." The foregoing discussions indicate that this is not always true, particularly for subdivisions of currents in branches, and is subject to exceptions in the ground and neutral paths, as stated, for double line to ground faults.

May we hope for further work in this field in the near future, including the consideration of saturation effects for example, and particularly in regard to relay applications.

REFERENCES

1. Simplified Calculation of Fault Currents. Report sponsored by AIEE committee on protective devices. *Electrical Engineering*, volume 61, 1942, pages 509–11, and AIEE *Transactions*, volume 61, 1942, pages 1133–5.

2. AIEE *Transactions*, volume 63, 1944, February section, pages 65–8.

3. AIEE *Transactions*, volume 60, 1941, September section, pages 877–81.

4. AIEE *Transactions*, volume 60, 1941, pages 1351–3.

GEORGE W. HAMPE (M '44)

(Engineer, testing department, Commonwealth Edison Company, Chicago, Ill.)

NEW BOOKS • • •

"ASTM Standards on Electrical Insulating Materials (with related information)." This compilation prepared by the ASTM committee D-9 gives in their latest form the more than 75 widely used specifications and test methods covering electrical insulating materials and related products. The committee is a working group under the ASA committee C-59 which is sponsored by ASTM and on which AIEE is represented by R. W. Atkinson (F '28) chief research engineer, General Cable Corporation, Bayonne, N. J., Doctor W. B. Kouwenhoven (F '34) dean, school of engineering, Johns Hopkins University,

Baltimore, Md., and H. W. Bousman (M '36) general engineering laboratory, General Electric Company, Schenectady, N. Y. Included also are several reports covering the significance of tests of insulating materials, a proposed method of testing askarels, and most recent recommendations affecting standards on electrical insulating materials. The reports discussing the tests cover dielectric strength, impact, tensile strength, power factor, resistivity, and for insulating liquids several others such as viscosity. American Society for Testing Materials, Philadelphia, Pa., 1945. 560 pages, 6 by 9 inches, paper, $3.25.

"Electronics for Engineers." This is a collection of 142 articles, reference sheets, charts, and graphs for design engineers, builders, and users of electronic equipment and component parts, reprinted in convenient and economical form from the pages of *Electronics*. Individual papers have been grouped into chapters for convenient reference to make the book practically self-indexing. The articles cover 27 subjects, including antennas, audio amplifiers, capacitors, cathode-ray tubes, and electronic heating. Edited by John Markus and Vin Zeluff. McGraw-Hill Book Company, Inc., New York and London, 1945. 390 pages, $6.

"Electronic Engineering Master Index" (first annual edition). This is a definitive guide to the radio-electronic engineering literature published during the past two decades. Part 1 covers the period from January 1925 to December 1934; part II, the period from January 1935 to June 1945. This compilation contains approximately 15,000 entries, the majority of which are the titles of all engineering articles that have appeared in the leading profesional periodicals and engineering periodicals in aeronautical, chemical, mechanical, and general industrial fields. Edited by Frank A. Petraglia. Electronics Research Publishing Company, New York, N. Y., 1945, cloth, 318 pages, $17.50.

LIBRARY

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

MAKING PATENT DRAWINGS. By H. Radzinsky. The Macmillan Company, New York, N. Y., 1945. 96 pages, 10½ by 7¾ inches, cloth, $3. Explicit instructions are given for shading, placement of numerals and figures, and other special techniques in making drawings both for patents and for trademarks.

INDUSTRIAL PLASTICS. Third edition (revised). By H. R. Simonds. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1945. 396 pages, 9¼ by 6 inches, linen, $5. Important new developments and processes are covered and a chapter is devoted to foreign practice. Design information suggestions for new applications and markets, and a revised trade-name index provide further useful material.

CHEMICAL FORMULARY. Volume 7. Edited by H. Bennett. Chemical Publishing Co., Brooklyn, N. Y., 1945. 474 pages, tables, 9 by 5½ inches, cloth, $6. Some 2,000 formulas are presented in this latest volume of a series. As with the rest of the series, none of the formulas has appeared in previous volumes. There is a list of sources of chemicals and supplies not readily available.

HISTORY OF PHOTOGRAPHY. By J. M. Eder, translated by E. Epstean. Columbia University Press, New York, N. Y., 1945. 860 pages, tables, 9¼ by 6 inches, cloth, $10. This comprehensive historical treatise is a translation of the fourth edition, 1932, of the original German work, and carries through the first quarter of the 20th century. It begins with an examination of the rudimentary knowledge of light and its properties held by the ancient Greeks and Romans and proceeds, century by century, through the discoveries and contributions of individuals from many nations.

MARINE ELECTRIC POWER. By Q. B. Newman. Third edition, Simmons-Boardman Publishing Corp., New York, N. Y., 1945. 244 pages, diagrams, charts, tables, 7¾ by 4¾ inches, cloth, $2.50. Avoiding the use of advanced mathematics and physics, this elementary text covers the essentials of electrical theory, the principles of electrical engineering, and the use of electric equipment on shipboard.

MEANING OF RELATIVITY. By A. Einstein. Princeton University Press, Princeton, N. J., 1945. 135 pages, diagrams, charts, tables, 8 by 5½ inches, cloth, $2.00. This is a reissue of Mr. Einstein's classic presentation of his theory of relativity. It is intended for the general reader who has some understanding of modern physics and advanced mathematics. The subject of space and time in prerelativity physics is discussed as well as the special and general relativity theories. An appendix, covering significant advances in this field since 1921, has been included in this new edition.

PLASTICS. Third edition. By J. H. DuBois. American Technical Society, Chicago, Ill., 1945. 447 pages, illustrated, 8½ by 5½ inches, cloth, $4.00. This book affords a simple, clear explanation of the manufacture of the more important plastics, discusses the manufacturing problems, and their principal applications.

AMERICAN CHEMICAL INDUSTRY, 1912–1922. Volume 2. By W. Haynes. D. Van Nostrand Company, New York, 1945. 440 pages, illustrated, tables, 9½ by 6½ inches, cloth, $8. This is the first of a projected six-volume history. The first five chapters describe the political and commercial setting of World War I period. The succeeding chapters cover developments in the field of critical raw materials such as nitrates. More than 100 pages of statistical data are appended.

APPLIED ENERGY CONVERSION. By B. G. A. Skrotzki and W. A. Vopat. McGraw-Hill Book Company, Inc., New York and London, 1945. 509 pages, illustrated, diagrams, charts, tables, 9 by 5¾ inches, cloth, $5. This text in power-plant engineering covers equipment and economics of industrial and central-station power plants. The newer developments in gas turbines and wind turbines, as well as special and European types of steam generators are included.

CALCULUS FOR PRACTICAL ENGINEERS. By A. Cibulka. Clarke and Courts, Houston, Tex., 1944. 100 pages, illustrated, diagrams, tables, 12 by 9¼ inches, paper, $3. Basic equations and functions are given from algebra through trigonometry, analytic geometry, differential and integral calculus to differential equations. The processes of differentiation and integration are described in simple, practical language, with applications to a number of actual and varied engineering problems.

DIESEL-ELECTRIC PLANTS. 2nd edition. By E. J. Kates. American Technical Society, Chicago, 1945. 272 pages, illustrated, diagrams, charts, tables, 8½ by 5½ inches, cloth, $3.75. The purpose of this book is to deal with the co-ordinated aspects of the specialized subject, owing to the influence of the characteristics of the Diesel engine on the electric equipment involved. Important topics covered include voltage regulation, automatic synchronizing, engine governors, automatic controls, electric starting, installation and maintenance practice, and Diesel-electric locomotives.

FUNDAMENTAL THEORY OF SERVOMECHANISMS. By L. A. MacColl. D. Van Nostrand Company, New York, 1945. 130 pages, diagrams, charts, 9¼ by 6 inches, cloth, $2.25. This book is concerned mainly with the general theory of automatic control which is applicable to all linear continuously operating servomechanisms, with emphasis on its identity with the theory of feedback amplifiers. Some particular servomechanisms are discussed briefly.

PAMPHLETS

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

German "Fasteners" Industry. Bolts, Screws, Nuts and Rivets. Investigated by Roy H. Smith, Charles F. Newpher. July 6–20, 1945. American Institute of Bolt, Nut and Rivet Manufacturers. Cleveland, Ohio, 31 pages.

Educational Guide to Refrigeration and Air Conditioning Training Facilities in the United States. American Society of Refrigerating Engineers, New York, N. Y., 1945, 27 pages.

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TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

A New Submersible Network Protector of Higher Rating

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DURING THE DEVELOPMENT of the original low-voltage a-c-network distribution system, preliminary studies indicated that the use of a relatively large number of medium-sized distribution transformers would provide the most flexible and most economical arrangement. Furthermore, very satisfactory operating experience with network systems of this type gave considerable justification for their use.

Obviously the network protectors required were also of relatively small size, since the continuous ampere rating and the interrupting rating were influenced by the size of the distribution transformers used. This meant that the majority of the protectors had continuous ampere ratings of 250 and 500 amperes at 60 cycles and interrupting ratings of 15,000 to 20,000 amperes at 220 volts.

However, the rapid growth of the a-c low-voltage-network distribution system, together with its adoption in many different types of application, soon developed the need for network protectors of considerably higher ampere ratings. The first expansion extended the continuous ampere ratings to 800 and 1,200 amperes. Subsequently the range was increased further to include 1,600- and 2,000-ampere ratings.

During this period the interrupting ratings remained at 20,000 amperes. But operating experience with systems having greater power concentrations, together with calculations of possible short-circuit currents, eventually led to the development of network protectors having interrupting ratings up to and including 40,000 amperes.

The need for the higher interrupting ratings also resulted from the use of spot networks requiring large concentrations of power and involving a number of large distribution transformers. In addition to having high interrupting ratings the network protectors for these applications required continuous ampere ratings as high as 3,000 amperes 60 cycles.

Most of the original network protectors were located in building or basement vaults not subject to flood conditions. This meant that the protectors could be mounted in the open air or in ventilated enclosures. Heat losses generated in the protectors therefore were dissipated readily, and it was not a difficult matter to provide reasonably compact units for any of the required ampere ratings.

Extension of the secondary network distribution system soon showed the desirability of installing network units in subway vaults either under the street or under the sidewalk. Installations of this type were of course subject to flood conditions, and both transformers and network protectors had to be made submersion proof. In the case of the network protectors, which were essentially automatic air circuit breakers, the enclosures had to be watertight, in fact airtight. Dissipation of heat from an airtight enclosure, with air inside the enclosure as the transfer medium, could occur only by straight conduction, convection, and radiation, with very little benefit from air flow.

This problem obviously becomes more difficult as the continuous ampere rating increases due to the greater heat losses developed. It is believed therefore that the problems involved and the methods used to produce a 3,000-ampere a-c submersible network protector of reasonable dimensions will be of interest.

General Description

The 3,000-ampere submersible network protector for 120–208-volt three-phase 60-cycle service is the latest development for application to secondary networks having highly concentrated load areas. The interrupting rating of this protector is 40,000 amperes. The accepted practice for network protectors requires that the circuit breaker withstand an initial instantaneous peak of $2^1/_4$ times the rms current which is to be interrupted, in this case a peak of 90,000 amperes, and requires that it carry the short-circuit current for 60 cycles before the current is interrupted.

The submersible network protector, as the term implies, is enclosed in a heavy steel housing suitably constructed to withstand submersion in water up to a depth of at least 15 feet and is in addition so constructed as to be readily accessible for maintenance. Figure 1 shows such a network protector completely closed as it is in service. The only electrical connections are those to the main circuit by means of the solid copper studs through porcelain bushings. The cover of the housing is a separate fabrication which is hinged, gasketed, and clamped to the tank body in such manner as to be readily

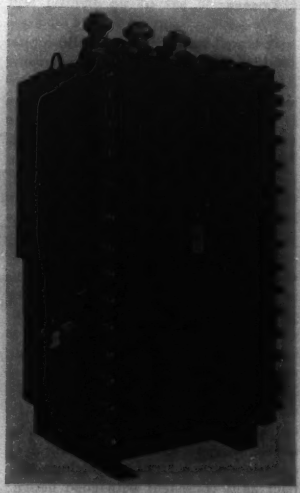

Figure 1. Submersible-type 3,000-ampere network protector for transformer mounting showing exterior cooling fins

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Figure 2. Submersible-type 3,000-ampere network protector for transformer mounting showing interior cooling fins

opened for access. The protector proper is a unit assembly which can be disconnected readily at top and bottom from the power circuit and rolled forward on collapsible tracks mounted within the housing. Briefly described, this protector unit consists of a three-pole motor-operated circuit breaker, three fuses, a master network relay, a phasing relay, and a desensitizing relay. See Figure 2.

Reduction of Copper and Iron Losses

It is well known that for solid copper conductors of a size suitable for carrying 3,000 amperes at 60 cycles there is considerable "skin effect" and also that there is considerable power loss in magnetic members in proximity to such conductors. Both of these factors are comparable to an increase in resistance of the conductor, and, as such, it is evident that the power loss within the protector varies directly as the square of the current carried. This is roughly a measure of the difficulty encountered in increasing the current-carrying capacity of the network protector without at the same time drastically increasing its operating temperature. It is impractical to increase the carrying capacity without some increase in total losses, and the dissipation of these additional losses through the housing to the outside air further complicates the heat problem. A network protector, like most electric equipment, must be made as compact as is consistent with good design; this mechanical requirement is in direct opposition to the tendency of higher currents to result in larger conductor sizes, higher magnetic forces on contacts, and, hence, larger mechanisms. It was the judicious balancing of these factors with certain improved arrangements which made the present development possible.

The phenomenon of skin effect is well known, and in general its effect is quite readily calculated.[1] However, in the case of a compact multiple-pole circuit breaker with its irregular current paths, proximity of adjacent phases, and proximity of magnetic materials the problem is complicated by proximity effect,[2,3] by iron losses, and by contact losses. Because of the indeterminate nature of the combined losses it was decided early to study the losses experimentally by measuring the actual a-c resistance of the circuit breaker and its parts. The loss in relay potential and current coils is a small part of the total, and hence the problem is entirely one of current losses, except for consideration of the temperature rise of the coils themselves. A search of the literature on the subject did not disclose a previously available method of readily and directly measuring the 60-cycle resistance of such heavy copper circuits. The method employed is described in the appendix.

Conductors of a size to carry 3,000 amperes at 60 cycles are most efficient when made in a tubular form, preferably of circular section, with a wall thickness of approximately 0.5 inch but specifically related to the actual diameter.[3] Because of practical considerations in arranging contacts and connections in limited space a hollow conductor of square section has been used for current-carrying parts wherever practical. Since these hollow conductors are open at each end and since they are mounted vertically, natural convection is effective for cooling inside as well as outside surfaces. (For a comparison of some typical conductors, see Table I.)

The movable contact or bridging member of the circuit breaker cannot readily take the form of a hollow conductor, especially in the limited space available in a network protector, and hence an alternate type of conductor had to be used here. The conductor used takes the form of six copper blades per pole in parallel, these being hinged at their lower end similar to the blade of a knife switch, and engaging stationary jaws at their upper end. The copper blades are arranged in pairs with three such pairs making up a bridging member for each pole. In each pair the blades are placed with the flat faces of one parallel to those of the other. The next pair is in a similar position but spaced approximately one inch away. This configuration of six flat bars in parallel if extended in length would have a current distribution over its cross section no better than would a solid conductor of the same outside dimensions. However, in this case each of the six conductors is only several inches in length and at each end there is a contact, the resistance of which is appreciable compared with that of each bar itself. The effect of these contacts is to equalize the current flowing through the six bars, and therefore the current distribution over the cross section

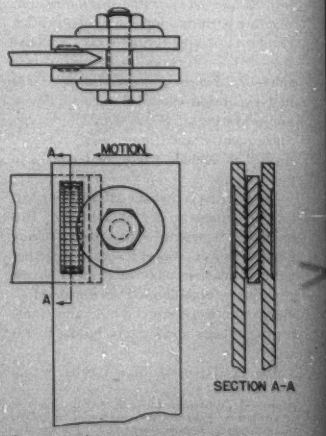

Figure 3. A view showing detail construction of the multiple silver-plated line contact at the break end of the bridging- or moving-contact members

of each bar is comparable with that which would flow in a single isolated bar, and all six bars carry current effectively.

At the hinge joint of each pair of bars the contact is a hard silver plate of substantial thickness on both the moving bars and on the stationary jaw which is placed between them. Pressure is applied to these contacts by means of a through bolt and cup-washer springs.

At the break end of the bridging members the stationary jaw is similarly silver plated and is tapered at its engaging edge to facilitate engagement with the moving bars. The bars, however, engage this jaw only for a portion of their width in order to conserve travel. The portion of a bar which engages the jaw at this point is silver-plated and then by high pressure dies is embossed into a series of parallel, raised, and hardened silver lines each with its axis in the direction of the sliding action of the contact. Figure 3 shows the arrangement of the embossed-silver multiple-line contact. Pressure on the break contact just described is secured in the same manner as at the hinge joint, that is, by means of a transverse bolt through the two bars and a cup-washer spring on either side. Figure 4 shows the construction of the circuit breaker.

Each pole of the protector is fitted with a fuse, usually on the network side, to serve as standby protection in case of apparatus failure or to open the circuit in case of a bad nonclearing fault on the network side close to the protector. These fuses are designed to operate at an unusually low temperature in order not to add unduly to the heat problems of the protector. Low operating temperature is obtained by constructing the fuse with a fusing member from a small section of low-melting-point eutectic alloy; the balance of the fuse body is heavy copper.

Network protectors commonly are enclosed in steel housings, and, because they are made as compact as practical, it is obvious that at some point the conductors will approach this steel enclosure or actually pass through it, resulting in hysteresis and eddy-current losses in the steel. These losses actually may equal or exceed the copper losses, unless preventive measures are taken. The method of measuring a-c losses which is described in the appendix was especially useful in tracing and eliminating these iron losses. It was found necessary to make the top plates where the main bushings pass through, and the rear plate of nonmagnetic steel. Also, mechanism brackets, levers and frames, and circuit breaker mechanical parts had to be nonmagnetic.

Heat Dissipation

When the circuit breaker has been developed to generate the minimum practical amount of copper and iron loss there still remains the problem of dissipating this heat through the steel housing or enclosure at the relatively small temperature differential which is available. The usual air circuit breaker has only copper loss to be dissipated and dissipates this by conduction, radiation, and convection directly to the surroundings; the usual oil circuit breaker by conduction to the oil and then by conduction, radiation, and convection to surroundings. The temperature differential available for the dissipation of heat is 85 degrees centigrade for class-*B* insulation.

The radiation of copper losses takes place in the network protector in three stages, namely, in one temperature drop from the copper to its barriers and immediate surroundings, in a second temperature drop from these surroundings to the inside of the enclosing housing, and in a third temperature drop from the housing exterior to surrounding objects. Similarly, in the dissipation of copper losses by convection it is found that there are three temperature drops in series, namely, first from the copper to the surrounding air, second from this heated air to the housing structure, and third from the housing to the exterior air. By conduction some heat is transmitted directly to immediate surroundings of the conductor and from there is taken by radiation and convection to the housing and to the outside; but the amount of copper loss which may be conducted directly to the housing structure is very small. Conduction through air to the housing walls accounts for a very small portion of the heat loss. Fortunately the iron losses which are allowed to remain are generated directly in the housing itself.

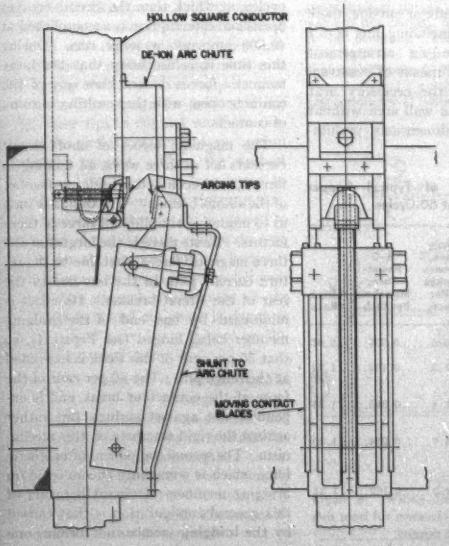

Figure 4 (left). A view showing the arrangement of circuit-breaker contacts and deion arc chute

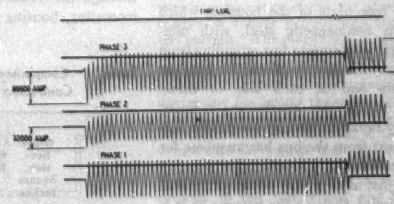

Figure 5. Oscillogram of a short circuit of 40,000 amperes at 300 volts, 60 cycles

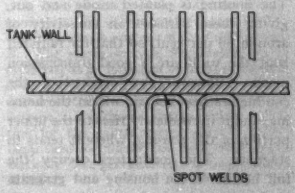

Figure 6 (right). Cross section showing arrangement of cooling fins

As radiation and convection are the chief factors in the dissipation of the copper losses, it is proper that all possible factors should be introduced into the design favoring the dissipation of the heat by these means.

The dissipation of heat by radiation is given by the Stefan-Boltzman law:

$$Q = 5.7 \times 10^{-12}(T_1^4 - T_2^4)\epsilon$$

where

Q = energy radiated, in watts per square centimeter
T_1 = absolute temperature of radiating body in degrees Kelvin
T_2 = absolute temperature of surrounding surfaces in degrees Kelvin
ϵ = total emissivity of surfaces

Since this quantity is proportional to the difference of the fourth power of the two absolute temperatures, it is evident that dissipation by radiation can be very useful even for small temperature differentials, provided the values of ϵ are as high as are practically obtainable. To this end the copper conductors are given an oxidized copper finish the emissivity of which is 56.8 per cent[3] as compared with unoxidized or unfinished metal surfaces which have an emissivity of four per cent or less. The housing surfaces, both interior and exterior, are finished with pigmented paints having even greater values of emissivity.

The convection factor for the removal of heat from the conductors is enhanced by taking advantage of the chimney effect of the vertical hollow conductors and by the bridging member of the circuit breaker being a number of thin conductors in parallel. The return bus bars at the rear of transformer-mounted network protectors are mounted on insulating members to the rear plate of the housing, which plate is nonmagnetic steel, with nonmagnetic steel cooling fins extending from the plate forward between the bus bar members and at each side of them. These fins, in this interleaving manner, both by radiation and by convection, extract heat from the bus bar members for their full length.

It is just as necessary to favor the heat transmission through the housing as it is to favor getting it out of the conductors. The housing is painted inside and out, giving these surfaces an emissivity of around 89 per cent, so that for radiated heat the walls are a good transmission means. However, by conduction the conductors heat the air within the housing, and it immediately rises to the upper portion of the housing, where it tends to stagnate. The conductors occupy the full height of the housing and generate

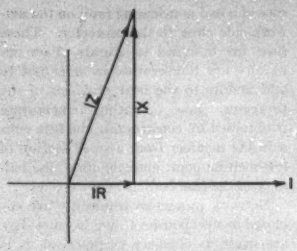

Figure 7. Diagram showing balancing of voltage components in the bridge circuit

I = test current
IR = inphase test voltage
IX = 90-degree test voltage
IZ = voltage drop of test specimen

heat for their entire length, so that the heated air tends to circulate upward past the conductors, and they get the benefit of true convection cooling. However, the heated air moving upward stagnates in the top of the housing and is cooled mainly by conduction through the housing walls. To cool this air and establish a full circulating system it is necessary to add greatly to the exposed surface of the housing, both internally and externally, in the hot region. This is done by adding cooling fins to both the inside and the outside surfaces as shown in detail in Figure 6, this being necessary only for approximately the upper one half of the housing. For each one square inch of base or radiating area, either inside or outside, there is an exposed area including fins of 5.1 square inches. The fin arrangement shown is a practical means of construction devised to get the necessary heat through the available wall area without increasing housing dimensions prohibitively; it is not theoretically correct in proportions, either in efficiency of a given amount of base surface or in the amount of metal used. Radiation alone is not sufficient to cool the conductors and housing, and it is not practical to load the conductors with cooling fins; therefore, it has been necessary to allow a relatively large temperature differential from the conductors to the air in the housing and to work toward smaller temperature drops from this air to the housing wall and from the wall to the outside air by heavily loading the housing walls with fins.[4,6,7]

Table I. Comparison of Typical Copper Conductors at 60 Cycles

	Gross Section, Square Inches	Surface, Square Inches Per Inch	A-C Resistance, Microhms Per Inch	R_{a-c} / R_{d-c}
1½x4 Solid bus[1]	5.00	10.5	0.327	2.07
4-inch hollow square ⅜-inch wall	5.24	27.3	0.193	1.22
3-inch hollow square ⅛-inch wall	4.37	17.4	0.245	1.35
3-inch outside diameter of tube ⅛-inch wall	3.93	15.7	0.224	1.30
4-inch outside diameter of tube ⅛-inch wall	5.50	22.0	0.162	1.31

Mechanical Features

Working in opposition to the requirements for low loss and low temperature rise, as well as the requirements for high interrupting ability and high short-time current rating, is the ever present need for minimum physical size. The methods used to accomplish the required temperature results have been described. The mechanical features whereby the stresses of interruption and of high currents are held under control now will be discussed.

The current values encountered in short-circuit interruption by network protectors are high and must be held under control until interruption is accomplished. The 3,000-ampere network protector is required to interrupt a short circuit, the initial crest of which reaches an instantaneous value of 90,000 amperes or more, followed by a decreasing current for 60 cycles, at which time the circuit breaker opens and interruption is accomplished at 40,000 amperes or more rms. During this time it is necessary that the large magnetic forces do not blow any of the contacts open, with the resulting burning of contacts.

The magnetic forces of short-circuit currents act in three ways, all tending to force open the contacts or bridging member of the circuit breaker. The design is such as to minimize or nullify all three of these factors. First, there is the largest of the three magnetic forces, that due to the return-current path in the bus bar to the rear of the circuit breaker. Its effect is minimized by one end of the bridging member being hinged (see Figure 4), so that 50 per cent of this force is expended at the hinge pin. The 50 per cent of the force at the contact or break end is expended, not against springs, but rather against the rigid members of the mechanism. The second component of magnetic force which is commonly encountered on bridging members of circuit breakers of this general configuration is that caused by the bridging member not forming one

straight conductor with the upper and lower conductors.[8,9] This component is minimized and controlled in the same manner as the first component and also is minimized further by the bridging member being closely in line with its terminal conductors. The third component of magnetic force tending to blow the contacts open is that due to the current converging to a small cross section and high density at points of contact. At any given point of contact this force will vary as the square of the current. This factor in the present circuit breaker arrangement is minimized by the current being divided into six contact paths (one for each of the six blades) and further into the multiplicity of line contacts at each embossed contact; the force at each detail contact will vary as the square of the current through it, but the sum of the squares of the individual currents is a value less than the square of the sum of the currents, which would be the case if the total current passed through a single contact. The effect is minimized further by the fact that the forces are in a direction 90 degrees to the main motion of the bridging member and further are more than counteracted by the cup-washer springs and by the magnetic forces of the parallel currents in each pair of blades tending to pull the blades together.

When the circuit breaker opens, the two side pairs of blades open first and transfer all of the current of one pole to the center pair which opens slightly later and in turn transfers the total current to be interrupted to the butt type of arcing contacts with tungsten-alloy arcing tips. The hinging of and flexible connection to this arcing contact are arranged so that the nonuniform magnetic field resulting holds these tips in contact until the motion of the circuit breaker and mechanism opens the contact. When the contact does open, the current is transferred to the deion arc chute for interruption. Once transferred the current is carried to the deion chute through a separate conductor for the purpose and no longer is carried by any of the circuit-breaker contacts. The general arrangement of the circuit-breaker and arc chute is shown in Figure 4.[10] Figure 5 is a typical oscillogram of an interruption.[10]

From the foregoing it is noted that the mechanism need only be large enough to close the circuit breaker against frictional forces and the forces of opening or accelerating springs. It is not required to deflect contact springs which (as commonly used in circuit breakers) are sufficiently strong to withstand directly the magnetic forces of short-circuit currents.

Appendix. Measurement of A-C Resistances at Low Frequencies in Heavy Conductors

In the case of commercial power frequencies the a-c resistance of heavy-current conductors, or the wattage of power resulting therefrom, normally is arrived at by calculation rather than by measurement. When the conductor is irregular in size and arrangement, or when return phases by proximity become factors, or when there is magnetic steel in the vicinity, calculations become tedious and often questionable. Frequently the conductors are so short that the voltage drop in their length is a matter of millivolts, even with several thousand amperes flowing, and normally the power factor through the conductor is very low. With these circumstances the problem does not lend itself to the use of the conventional wattmeter. Further complications arise from induced voltages in the potential circuits by reason of the proximity of the heavy-current circuits.

The method of measuring wattage loss developed in conjunction with high-current network protectors is based on the use of a bridge circuit wherein the voltage drop across the test specimen is balanced by a voltage made up of two components, both variable in magnitude, one component known to be inphase with the test current and the other known to be 90 degrees out of phase with the test current. See Figure 7. By calibration of the source of the inphase component the effective resistance of the specimen is determined.

The test circuit is shown in Figure 8 in diagram form. The source of test energy is a transformer of the required frequency capable of circulating several hundred amperes through the test specimen; the current value is not critical, nor is it necessary that it be constant. The test current from terminals *A–A* is circulated through a current transformer *C*, through the test specimen *B–B*, and through a section of concentric conductor *D* (shown in section), the latter being heavily shielded magnetically. All test circuits other than the source of heavy current are of the concentric shielded type. The secondary of the current transformer is connected to a potentiometer type of resistor having a double-contact type of slide *SH* and designed to have very low reactance and very low skin effect at the frequency used.[11] This potentiometer is the source of a voltage, adjustable in magnitude, which is closely inphase with the current in the primary of the current transformer, and hence is closely inphase with the *IR* component of the voltage drop through the test specimen. The position of the double-contact slide is calibrated in terms of the d-c resistance of the section of conductor which is included between the two contacts. When a balance is established (described later), the a-c resistance of the test specimen is known to be the d-c resistance of the potentiometer at the particular setting divided by the ratio of the current transformer. From the foregoing it is evident that

1. The potentiometer must have no appreciable skin effect.
2. The current transformer must have very little phase-angle error.
3. The ratio of the current transformer under load must be accurately known.

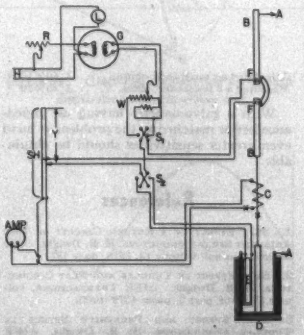

Figure 8. Wiring diagram of the bridge circuit used for measuring a-c resistance of large copper conductors

In order completely to balance the voltage drop appearing at *FF* across the test specimen it is necessary to obtain a voltage which is variable in magnitude and which is known to be accurately 90 degrees inphase position relative to the test current. This is obtained by induction from coil *E* which is mounted pivotally in the annular space between the inner and the outer conductors of the concentric conductor *D*. The 90-degree relation is known to obtain, because the magnetic flux in the annular space is of necessity inphase with the current in the central conductor, and the voltage induced in coil *E* leads this flux by 90 degrees. These phase-angle relations hold accurately for conditions of balance, for then there is no current flow in the galvanometer circuit which could upset the angular relations. The coil *E* is wound upon an entirely nonmetallic structure and is wound of very fine wire in order not to distort the phase-angle relation of voltage induced with respect to test current. The magnitude of voltage to secure a balance is obtained by adjusting the plane of coil *E* with respect to a plane described by a radius of the concentric conductor and the axis of the same conductor.

By means of shielded cable, voltages from *SH* and from *E* are connected in the same circuit with the voltage from test specimen *FF* and with vibration galvanometer *G*. Double-throw switches *S1* and *S2* permit of reversal of test connections and thereby eliminate some minute effects of stray fields upon the test specimen. Rheostat *W* controls the sensitivity of the vibration galvanometer. The galvanometer is tuned to the test frequency by means of the field rheostat *R*. The vibration type of galvanometer is preferred as an indicator of balance because of its fine sensitivity and because of its freedom from the effects of harmonics in the test current. *H* is the d-c source of field excitation for the galvanometer, and *W* is the lamp used for mirror and light-beam registration. The galvanometer is magnetically shielded.

The Solution of Transmission-Line Problems in the Case of Attenuating Transmission Line

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COAXIAL LINES with solid dielectric often are used as feeders. Such lines have appreciable attenuation (of the order of 1.5 decibels per 100 feet at 100 megacycles per second). Application of standing-wave method of finding the receiving-end impedance, as based on the assumption of lossless transmission line, would introduce an appreciable error, increasing with the length of the line used. The purpose of this paper is to show how by the application of the standard transmission-line theory the standing-wave method of measuring impedance can be extended to the case of transmission lines with attenuation, if the appropriate corrections are introduced. As seen from this point of view, the paper brings together and somewhat systematizes information available in the existing technical literature.[1,2]

Voltage Distribution Along the Line

The total complex voltage V at any given point of the transmission line is the sum of the incident complex voltage V_i and the reflected complex voltage V_r. As we go along the attenuating transmission line from its receiving toward its sending end, the amplitude of the incident vector voltage increases. This is taken into account by the multiplication of the reference magnitude V_i by $e^{\alpha x}$. Hence, at the point x from the receiving end the incident voltage has the magnitude $V_i e^{\alpha x}$ (Figure 1). The factor α is called the attenuation constant of the line.

Also, if we go along the attenuating transmission line from the receiving toward the transmitting end, the phase of the incident complex voltage changes. This is again taken into account by the multiplication of the reference magnitude by $e^{j\beta x}$. Hence, at the point x from the receiving end the incident complex voltage is $V_i e^{\alpha x} e^{j\beta x}$ (Figure 2).

The factor β is called the phase constant of the line. As we see, the simultaneous attenuation and phase shift can be taken into account by multiplying the reference magnitude V_i by $e^{\gamma x}$ (Figure 3) where $\gamma = \alpha + j\beta$. The factor γ is called the propagation constant of the line. Hence the general expression of the incident voltage at point x from the receiving end of the line is $V_i e^{\gamma x}$.

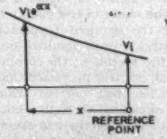

Figure 1 (left). Effect of attenuation

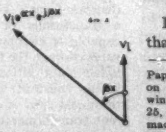

Figure 2 (right). Effect of phase shift

Similarly the reflected complex voltage at the point x from the receiving end of the line can be represented by $V_r e^{-\gamma x + j\psi_r}$, where V_r is the magnitude of reflected voltage at the receiving end of the line and ψ_r its phase difference in relation to the incident voltage at the receiving end (Figure 4).

Hence the total complex voltage at the point x from the receiving end of the line is

$$V = V_i + V_r = V_i e^{\gamma x} + V_r e^{-\gamma x + j\psi_r} \qquad (1)$$

The ratio of the reflected complex voltage at the receiving end to the incident complex voltage at the same point is called the voltage complex reflection coefficient K_R:

$$K_R = K_R e^{j\psi_r} = \frac{V_r}{V_i} e^{j\psi_r} \qquad (2)$$

Introducing this into equation 1 we obtain

$$V = V_i (e^{\gamma x} + K_R e^{-\gamma x}) = V_i e^{\gamma x}(1 + K_R e^{j\psi_r} e^{-\gamma x}) \qquad (3)$$

Voltage Distribution Near the Receiving End

Let us assume, as a first approximation, that, although the line is attenuating, the

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In the use of this test circuit the current is adjusted to any suitable value at the desired frequency, and balance is obtained by adjustment of SH and E until zero response is obtained on galvanometer G. Rough balance is made first with W large and then the sensitivity gradually increased as closer and closer balance is achieved. When balance is reached the a-c resistance of the test specimen is the d-c resistance of section Y of the potentiometer divided by the ratio of the current transformer.

Although the test arrangement described was used on appreciably heavier conductors, actual comparison with values calculated for a ten-inch length of seven-eighths-diameter copper bar was made as follows:

D-c resistance of ten-inch length, ohms	1.315×10^{-4}
Ratio of a-c–d-c resistance	1.0668
Calculated a-c resistance, ohms	1.40×10^{-4}
Measured a-c resistance, ohms	1.45×10^{-4}

With a galvanometer having an impedance better matched to the problem at hand even greater sensitivities should be obtainable.

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11. RESEARCH PAPER 133, United States Bureau of Standards.

attenuation of the line of a length of about $\lambda/2$ is negligible. Let us find the voltage distribution along the first half wave length of line from the receiving end. According to our assumption for this length $e^{\alpha x} \longrightarrow 1$ and from equation 3 we obtain

$$V = V_R e^{j\beta x}(1 + K_R e^{j\psi_0} e^{-j2\beta x}) \qquad (4)$$

This is a well-known[3] equation of the voltage distribution along the lossless line. The expression in the brackets on the right side of the last equation is the vector sum of the unit vector OA (Figure 5a) drawn along the real axis and the vector $AB = K_R e^{j(\psi_0 - 2\beta x)}$ drawn from the point (1.0) as shown on the same figure. The vector $K_R e^{j(\psi_0 - 2\beta x)}$ rotates, with increasing x, in the clockwise direction and completes one revolution when $x = \lambda/2$ (since the phase constant $\beta = 2\pi/\lambda$).

To find the magnitude of this vector sum in the brackets for a given length of line x, we must rotate the vector K_R through the angle $2\beta x$ from its original position and in the clockwise direction. Let us assume that x is such that the vector takes the position AB in Figure 5a Then the segment OB gives us the magnitude of the vector sum. Moreover, this magnitude is proportional to the magnitude V of total complex voltage at the point x, of the line, since the factor $e^{j\beta x}$ before the brackets changes only the phase angle.

In Figure 5b the magnitude of the vector sum in the brackets versus the length x of the line is plotted. According to what has just been said, this also gives the distribution of the magnitudes of the total voltage along the line.

Voltage Distribution Far From the Receiving End

Let us suppose that the line under consideration is terminated in such a load that the receiving-end-voltage reflection coefficient and voltage distribution are as shown in Figures 5a and b.

Let us find the voltage distribution on the line starting at some distance $x_2 = n(\lambda/2)$ where $n \gg 1$. Since, according to our previous assumption, the attenuation though existing is constant along the considered $\lambda/2$ section of the line, the equation 3 yields

$$V = V_R e^{\alpha x_2 + j\beta x}(1 + K_R e^{j\psi_0} e^{-2\alpha x_2} e^{-j2\beta x}) \qquad (5)$$

We shall use again the graphical construction. On the real axis (Figure 6a) we shall plot the unit vector OA. Then, using point A as a center, we shall draw the circle of the radius $K_R e^{-2\alpha x_2}$. The

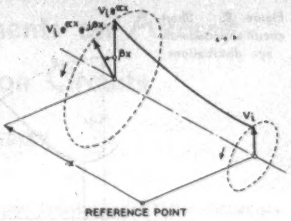


Figure 3. Effect of attenuation and phase shift

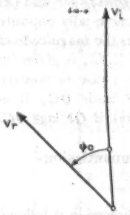


Figure 4. Incident and reflected voltages at the receiving end of the line

vector AC will be equal to $K_R e^{-2\alpha x_2} e^{j\psi_0}$. The magnitude of the vector OC is proportional to the magnitude of the total voltage at the point x_2 of the line. By rotating the vector AC in the clockwise direction and in the way just explained, we obtain again the voltage distribution on the section of line considered. This voltage distribution is plotted in Figure 6b

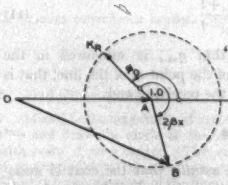


Figure 5a. Graphical construction for voltage distribution near receiving end

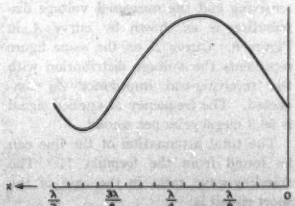


Figure 5b. Voltage distribution near receiving end

versus the distance along the line. Comparing the Figures 5b and 6b (when plotted to the same scale), we see that the voltage distribution farther from the receiving end of the line differs from that at the receiving end in two respects:

1. Farther from the receiving end the standing-wave ratio q, that is, the ratio of maximum to minimum voltage, decreases. In other words the attenuation of the line decreases the standing-wave ratio q.

2. The space average magnitude of the voltage is higher farther from the receiving end.

Attenuating Line as an Impedance-Measuring Device

For the voltage distribution starting at the point x_2 of the line (far from the receiving end), the maximum magnitude is

$$V_{max} = V_R e^{\alpha x_2}(1 + K_R e^{-2\alpha x_2}) \qquad (6)$$

and the minimum magnitude is

$$V_{min} = V_R e^{\alpha x_2}(1 - K_R e^{-2\alpha x_2}) \qquad (7)$$

Hence the standing-wave ratio in the vicinity of the point x_2 is

$$q_2 = \frac{V_{max}}{V_{min}} = \frac{1 + K_R e^{-2\alpha x_2}}{1 - K_R e^{-2\alpha x_2}} \qquad (8)$$

Solving the foregoing for K_R yields

$$K_R = e^{2\alpha x_2} \frac{q_2 - 1}{q_2 + 1} \qquad (9)$$

The last equation gives us the magnitude K_R of the receiving-end-voltage reflection coefficient. This can be used now to find from the known formula[3] the standing-wave ratio q_R near the receiving end of the line:

$$q_R = \frac{1 + K_R}{1 - K_R} \qquad (10)$$

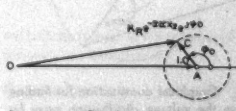


Figure 6a. Graphical construction for voltage distribution far from receiving end

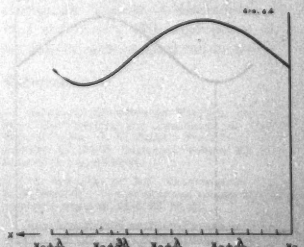


Figure 6b. Voltage distribution far from receiving end

This standing-wave ratio, together with relative shift of the voltage minimum in relation to the point x_2, can be used in the standard way[1] to find Z_R/Z_o from the appropriate chart (Z_R equals the receiving-end (load) impedance; Z_o equals the characteristic impedance of the line).

If we prefer the graphical construction, we can proceed as follows: Suppose that the vector ***OB*** in Figure 7a is proportional to the first minimum voltage encountered along the line when going from the point x_2 toward the sending end, whereas the vector ***OD*** is proportional to the maximum voltage. The circle with center A midway between the points B and D and going through these points is the locus of the reflected voltage near the point x_2 of the line. If the first minimum of the voltage is shifted a distance x_3 from the point x_2 (Figure 7b), then the corresponding angle is $2\beta x_3$. We shall rotate the vector ***AB*** counterclockwise through this angle $2\beta x_3$; this yields the vector $K_R e^{-j2\alpha x_3} \times e^{j\psi_2}$ proportional to the reflected voltage at the point x_2 of the line. Its magnitude is given by $K_R e^{-2\alpha x_3}$. Let us suppose that the attenuation constant α and the distance x_3 are known, then the factor $e^{2\alpha x_3}$ can be calculated. The multiplication of the magnitude $K_R e^{-2\alpha x_3}$ by the factor $e^{2\alpha x_3}$ gives obviously K_R.

Let us draw the circle of the radius K_R with a point A as a center. Then the vector ***AF*** gives us the reflection coefficient at

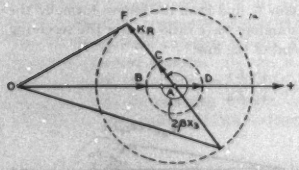


Figure 7a. Graphical construction for finding Z_R/Z_o from the voltage distribution curve far from receiving end

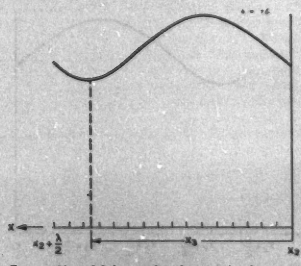
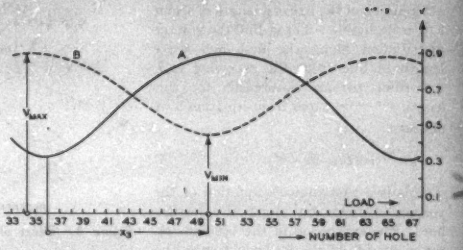


Figure 7b. Voltage distribution far from receiving end

Figure 8. Short-circuit and load voltage distributions



the receiving end of the line. As it is known, the ratio of segments OF and OG (the point G being diametrically opposite to the point F) gives us the magnitude of Z_R/Z_o. The phase of Z_R/Z_o is given by the angle GOF. This phase is positive (Z_R inductive), if ***OF*** leads ***OG***; it is negative (Z_R capacitive), if ***OF*** lags ***OG***.

Determination of Transmission-Line Attenuation

From the previous discussion it follows that the measurement of the receiving-end impedance Z_R requires among other things a knowledge of the attenuation constant α of the line.

The constant α can be determined readily from the measurement of the voltage distribution on the line when short-circuited at the receiving end. In this case, as we know, the magnitude K_R of the voltage reflection coefficient is equal to one and equation 9 yields

$$e^{2\alpha x_3} = \frac{q_{sh.c}+1}{q_{sh.c}-1} \qquad (11)$$

Note that $q_{sh.c}$ is measured in the vicinity of the point x_2 of the line, that is far from the receiving end.

Example

Let us assume that the coaxial measuring section of transmission line is connected through a long coaxial line to the unknown receiving-end impedance Z_R. When the line is short-circuited at the receiving end the measured voltage distribution is as shown by curve A in Figure 8. Curve B on the same figure represents the voltage distribution with the receiving-end impedance Z_R connected. The frequency of applied signal is 96.3 megacycles per second.

The total attenuation of the line can be found from the formula 11. The standing-wave ratio in the case of the short circuit is

$$q_{sh.c} = \frac{0.905}{0.32} = 2.83$$

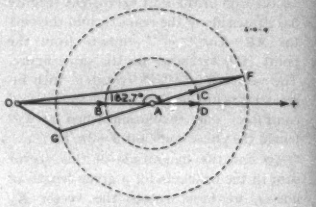


Figure 9. Graphical construction for finding Z_R/Z_o

Hence

$$e^{2\alpha x_3} = \frac{2.83+1}{2.83-1} = 2.1$$

That is, the total attenuation $\alpha x_3 = 0.37$ *nep* or 3.2 decibels.

In the case of the load connected the measured standing wave ratio is

$$q_3 = \frac{0.90}{0.445} = 2.02$$

The standing-wave ratio at the receiving end can be found from the known formula [1] using formula 9 as

$$q_R = \frac{1+2.1\,\dfrac{2.02-1}{2.02+1}}{1-2.1\,\dfrac{2.02-1}{2.02+1}} = 5.9$$

This example was chosen intentionally to show how important the correction of standing-wave ratio for the attenuation on the line between the measuring section and the receiving end can be.

The shift of the minimum when the line is loaded as referred to the minimum when the same line is short-circuited is $x_3 = 14$ holes, Figure 8, (Coaxial measuring section is provided with equidistant holes for the purpose of measuring voltage distribution. These holes are numbered and distances along the measuring section are measured conveniently in number of holes), or 0.226λ (since $\lambda = 64$ holes, as can be found from the curve B on Figure 8) toward the load. Hence the load is inductive.

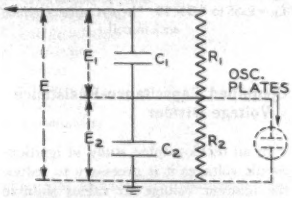
Electrical Measurements on Aircraft-Engine Ignition Circuits

WM. E. BERKEY
MEMBER AIEE

Synopsis: A method of measuring ignition voltages with a cathode-ray oscillograph is described. Magneto and spark-plug voltage oscillograms covering several consecutive firing pulses were taken on a complete aircraft magneto ignition system under several engine operating conditions. Oscillograms taken with spark plugs firing in air show differences when compared with engine tests. An improved electronic oscillograph has been developed which is well adapted for ignition measurements.

THE spark ignition system is recognized as the greatest single source of trouble in an aircraft engine.[1] New ignition problems have been created, and old ignition troubles intensified in modern engine developments. The ignition system on the high-power engines of today must function under higher output per cylinder, higher temperatures, greater numbers of firing sparks per second, higher altitude operation, and more stringent radio-interference requirements. The fact that large numbers of high-power aircraft engines are in operation today reflects great credit to the ignition engineers who have succeeded in solving their major problems.

A magneto ignition system generates and distributes a series of timed transient electric discharges. The magneto output voltage is created by a sudden disturbance in two coupled circuits each simply oscillatory, and, therefore, may be regarded as the resultant of two normal modes of different amplitudes, frequencies, and damping. A distributor alternately connects the different length spark-plug circuits with the magneto through a short air gap. The current which flows in the circuit then is complicated by the magneto characteristics, the variable circuit parameters, and the spark-dis-



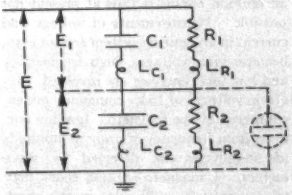
A—Simple resistor-capacitor divider

$$\frac{E_1}{E_2}=\frac{R_1}{R_2}=\frac{\frac{1}{\omega C_1}}{\frac{1}{\omega C_2}}=\frac{C_2}{C_1}$$

$$R_1C_1=R_2C_2$$

$$\frac{E}{E_2}=\frac{E_1+E_2}{E_2}=\frac{R_1+R_2}{R_2}=\frac{\frac{1}{C}+\frac{1}{C_2}}{\frac{1}{C_2}}=\frac{C_1+C_2}{C_1}$$

C_2 includes capacitance in plate circuit



B—Resistor-capacitor compensated divider

$$\frac{L_{R_1}}{R_1}=\frac{L_{R_2}}{R_2}$$

$$C_1L_{C_1}=C_2L_{C_2}$$

$$\frac{L_{C_1}}{R_1}=\frac{L_{C_2}}{R_2}$$

$$R_1C_1=R_2C_2$$

Figure 1. Parallel capacitor-resistor type voltage divider

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The engine tests described in this paper were made at the Pratt and Whitney Aircraft Division, United Aircraft Corporation plant, East Hartford, Conn. The co-operation of Val Cronstedt, executive engineer, E. K. von Mertens, project engineer, and the entire ignition group is gratefully acknowledged.

Using the transmission-line calculator,[4] we shall find that the resistive component R_R and reactive component X_R of the receiving end impedance Z_R are $R_R/Z_o=3.3$, $X_R/Z_o=2.9$.

The graphical construction for this case is shown in Figure 9. It consists of the following steps:

1. Draw OB proportional to V_{min} from Figure 8, curve B.
2. Draw OD proportional to V_{max} from Figure 8, curve B.
3. Draw the circle on BD as a diameter (point A is its center).
4. Translate the shift of the minimum x_1 into the angle $2\beta x_1$. In the case considered, since x_1 is shifted toward the load, the vector BA should be rotated clockwise. The angle of rotation is equal to $4\pi x_1/\lambda$. In the case considered it is 2.84 radians or 162.7 degrees.
5. The vector AC is proportional to $K_R e^{-2\alpha x_2} e^{j\psi_r}$.
6. Find $e^{2\alpha x_2}$ from formula 11.
7. Multiply the magnitude of vector AC by $e^{2\alpha x_2}$ and draw the circle of the radius K_R with point A as a center. The vector AF is proportional to the reflection coefficient K_R at the receiving end of the line.
8. The ratio of the segments OF/OG gives us the magnitude of Z_R/Z_o.
9. The angle GOF gives us phase of Z_R/Z_o

$$\frac{Z_R}{Z_o}=4.36$$

$$\left/\frac{Z_R}{Z_o}=42 \text{ degrees}\right.$$

or

$$\frac{R_R}{Z_o}=3.22$$

$$\frac{X_R}{Z_o}=2.92$$

As we see, these figures agree fairly well with those obtained when using the transmission-line calculator.

Conclusion

As it is seen, the existence of attenuation in the transmission line does not change the method of determining the load impedance; with appropriate connection the same method can be used.

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Figure 2. Pratt and Whitney aircraft ignition test assembly

M—Magneto; *D*—Distributor; *P*—Plug mount

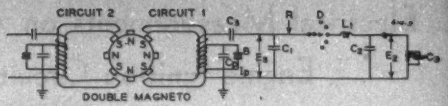


Figure 3. Magneto-ignition circuit constants

C_S = 2,000-micromicrofarad series capacitor
C_P = 0.35-microfarad primary capacitor
C_1 = 150-micromicrofarad capacitance of secondary to ground at distributor
C_2 = 100- to 300-micromicrofarad capacitance in harness and plug lead
C_3 = 35-micromicrofarad capacitance of spark plug
E_S = 25,000 volts maximum secondary open circuit volts
E_P = 85 volts maximum primary volts
L_P = 2.65 to 4.3 × 10^{-3} henrys primary inductance in coil
L_S = 30 to 42 henrys secondary inductance in coil
L_1 = 0.004 microhenry per centimeter in concentric cable (calculated)
I_P = six amperes crest
F_S = 2,000 approximate natural frequency with *D* open and *B* open
F_P = 6,000 approximate natural frequency with *D* open and *B* closed
F_1 = 10^7 cycles per second approximate frequency of $C_1L_1C_3$ (calculated)
R_S = 6,800 ohms
R_P = 0.25 ohms

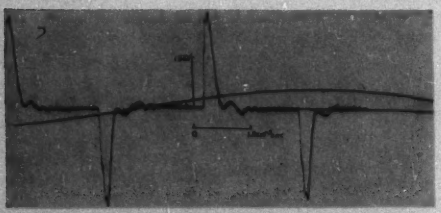
charge characteristics in both the distributor and spark plug. Calculation of an ignition circuit is thus at present not possible. Measurements of voltage and current in an ignition system are not easy, because high voltages, high frequencies, and low total energies are involved. Ignition voltages of 15 kv commonly are encountered at the magneto. Ignition currents from frequency of firing to hundreds of megacycles are detected by wave meters. A magneto ignition spark may release only 50 millijoules in the spark gap.[2]

The object of this paper is to describe some recent measurements made on a modern aircraft-engine ignition system with the hope that further investigation will be stimulated.

Combined Capacitance-Resistance Voltage Divider

In an oscillographic study of ignition-circuit voltages it is necessary to reduce the ignition voltage to values suitable for the oscillograph deflection plates. The construction of a divider, which will not change the ignition voltage being measured and will reproduce faithfully the ignition wave on the film, constitutes a major problem. A noninductive resistance divider of ten megohms total resistance gave frequency distortion due to the oscillograph plate capacitance of 25 micromicrofarads. Capacitance dividers were found to be unsatisfactory for low-frequency measurements due to unequal leakage around the capacitors. In ignition circuits both high- and low-frequency voltages are known to be present; therefore, a combined capacitance-resistance divider was built.

The simple capacitance-resistance divider is sketched in Figure 1A. When the time constants for each divider step are made equal, the frequency of the voltage being measured has no effect upon the ratio of the divider if the lead inductance is neglected. The effect of lead



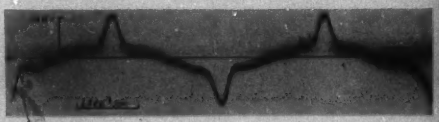


Figure 4. Open-circuit magneto voltages

A (left)—Open-circuit secondary voltage
B—Open-circuit secondary voltage with primary-circuit open

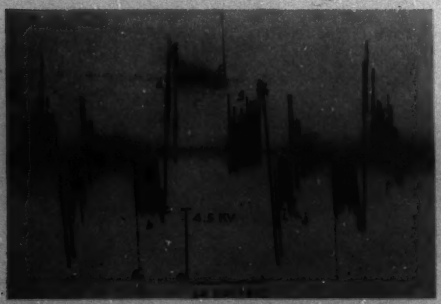
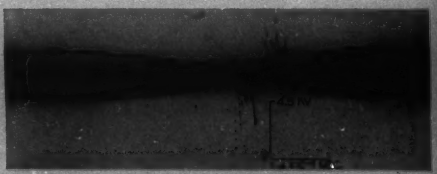


Figure 5. Distributor and plug voltage characteristics

A (left)—Distributor voltage to ground
B—Spark-plug voltage to ground



inductance is considered in the compensated divider of Figure 1B. With complete compensation it is possible to make a divider with constant ratio for direct current and high frequency.[3]

In the experimental investigation, the simple capacitance-resistance divider was found satisfactory. The constants of one divider were

$R_1 = 11.2 \times 10^6$ ohms $\quad C_1 = 25 \times 10^{-12} F$
$R_2 = 0.8 \times 10^6$ ohms $\quad C_2 = 350 \times 10^{-12} F$

It is necessary to keep the stray ground capacitance of R_1C_1 step low and to locate the divider as closely as possible to the point of voltage measurement.

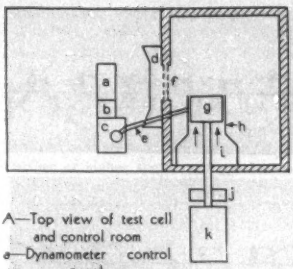
Ignition Assembly Tests

The ignition system investigated was that used on the Pratt and Whitney *R*-2800 18-cylinder engine. It consists of a double magneto, which generates simultaneous ignition pulses for two circuits of 18 plugs each through the two separated distributors. Initial tests were made with this ignition system mounted upon an engine nose section with plugs firing in air as shown in Figure 2. The standard magneto and distributor gears were driven by an electric motor mounted in the rear. The magneto was an eight-pole rotating-magnet type with two coils and breaker structures. The magneto rotor was geared to rotate at $1^1/_8$ times crankshaft speed. The breaker cam had 18 lobes ground for compensated timing and rotated at one-half crankshaft speed. A series capacitor of 2,000 micromicrofarads in the coil secondary, located in the magneto housing, enables the magneto to deliver more than 1,350 rpm×18=24,300 firing discharges per minute through each circuit. The voltage divider was attached to a spare high-voltage terminal provided in the magneto housing. A schematic circuit of this ignition system is drawn in Figure 3. The circuit constants measured and calculated for this circuit are listed below the circuit diagram.

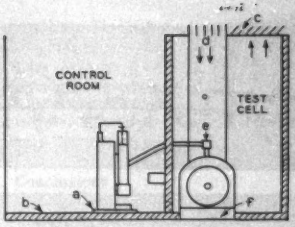
The rotating-film cathode-ray oscillograph[4] recorded the magneto and spark-plug voltage transients. The low-voltage side of the divider led directly to the deflection plates. The time scale was provided by rotation of the film. An exposure was made by unblocking the beam relay for a predetermined time with a voltage applied and removed by mechanical contactors.

The open-circuit voltage obtained on the magneto with the divider connected directly to the high-voltage side of the coil secondary is shown in Figure 4A. The open-circuit voltage rises to 28-kv crest with an initial rate of rise of about 400 volts per microsecond. The two frequency components of 2,000 and 6,000 cycles are visible in this oscillogram. Figure 4B shows the open-circuit voltage record obtained with the circuit breaker blocked open and the divider connected directly to the magneto.

The distributor voltage to ground obtained with the complete ignition circuit, but with the spark plugs firing in air, is shown in Figure 5A. The voltage rise at point *a* occurs when the primary circuit breakers open and the value of this crest voltage is determined by the breakdown voltage of the distributor gaps. The electric charge stored in the magneto secondary circuit up to the distributor then is shared with the spark-plug circuit on a high-frequency transient. The resultant voltage is usually high enough to break down the spark plug and discharge the secondary on a high-frequency damped-current oscillation. The air gaps then partially recover some dielectric strength, and the secondary circuit rises again, but now the voltage required to break down the distributor gaps is less than the initial breakdown, probably due to residual ionization in the gap. This action is repeated many times at *b* until finally at *c* the generated secondary voltage is no longer able to break down the gaps. The voltage reverses as a result of the buildup of reverse flux through the magneto coil, and at *d* several breakdowns occur. At *e* the primary circuit breaker closes, and the distributor spark goes out, leaving the high-voltage lead with a trapped charge because of the secondary series capacitor.

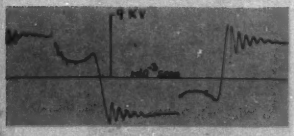


A—Top view of test cell and control room
a—Dynamometer control panel
b—High-voltage d-c rectifier
c—Oscillograph and control panel
d—Engine-control panel
e—Transmission line
f—Double window
g—Test engine
h—Shroud
i—Air blower
j—Water brake
k—Dynamometer

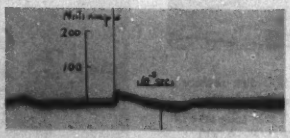


B—Side view of test cell and control room
a—Shock mount
b—Concrete floor
c—Roof vents
d—Air
e—Potentiometer
f—Bed plates

Figure 7. General layout for engine test



A—Type-*A* discharge voltage



C—Type-*A* discharge current at plug; restrike on flux reversal

B—Type-*B* discharge voltage

D—Type-*B* discharge current at plug

Figure 6. Voltage and current oscillograms of two types of ignition discharges

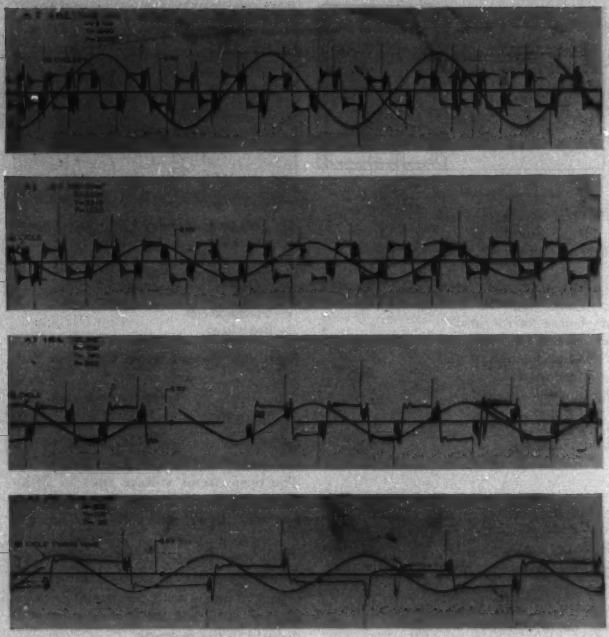


Figure 8. Magneto voltage with different engine-operation conditions

S—Speed, rpm
T—Indicated torque
P—Brake horsepower

A (above)—Typical oscillogram
Al-217 number-1 front plug
S—1,500 rpm idling

B—Effect of 15,000-ohm resistor in high-voltage lead at distributor
Al-268, number 1 rear plug take-off
S—2,700, *T*—2,900, *P*—2,000
R_s = 15,000 ohms at distributor

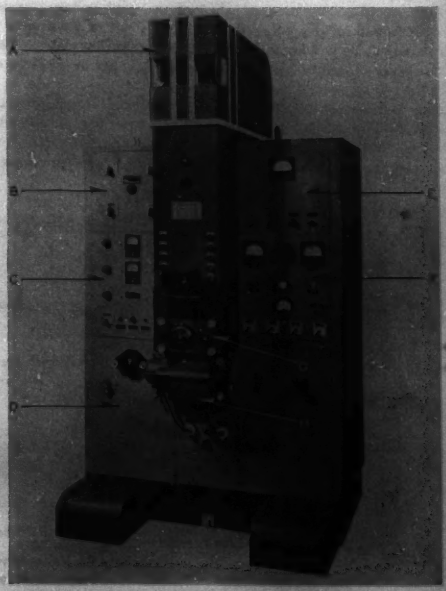
Figure 9. Spark-plug voltage records obtained during engine tests

Secondary voltage oscillations attributed to primary-current short-circuit transients are superimposed upon the residual direct voltage of this line section. At *f* the next pulse occurs on opposite polarity with the rotating distributor finger now adjacent to the next spark-plug circuit terminal. Repeated voltage rises and breakdown occur at *g*, the secondary magneto voltage reverses at *h*, and a second breakdown period is found at *i*, followed by the primary circuit breaker closing at *j*. This time the magneto–distributor lead was left at almost zero direct potential, although the a-c oscillations are relatively large.

An oscillogram of the spark-plug voltage is shown in Figure 5B. Two ignition discharges of opposite polarity taken on the same plug are recorded. Repeated charging- and breakdown-voltage varia-

Figure 10 (below). Westinghouse electronic oscillograph

A—Cathode housing, 50 kv, d-c maximum
B—Sweep and timing circuits
C—Focusing and bias control
D—Vacuum pumps
E—Calibrating and film-drum exposure control
F—Main control panel
G—Stationary film
H—Rotating film



tions are observed on the film. Also complicated reflection and extinction effects are indicated in this oscillogram.

Two types of magneto firing-voltage records were recorded on the assembled ignition system with spark plugs firing in air. Figures 6A and C illustrate typical voltage–time and current–time oscillograms associated with the steady type-A discharges. Figures 6B and D show oscillograms of voltage and current associated with the intermittent type-B discharges. Other investigators[5,6] have called these discharge types "inductive" and "capacitive" sparks. The steady sparks appear reddish and diffuse, whereas the intermittent sparks appear bright bluish and concentrated.

Ignition Tests on Engine

The layout of the test cell and control room is sketched in Figure 7. The test engine was loaded with a dynamometer and a water-wheel brake. A cathode-ray oscillograph was set up in the control room with a two-wire transmission line connecting the deflection plates to the voltage divider located over the engine. The length of the line was 12 feet. The test engine was operated under several fixed conditions, and records made of the magneto firing voltage and the spark-plug voltage to ground. In Figure 8 typical records of the magneto high-voltage lead voltage to ground are shown. A 60-cycle voltage was recorded to provide calibration of each oscillogram. An external mechanical relay used in these tests to trigger the beam frequently bounced to cause apparently unconnected short portions of the trace.

The intermittent-type discharge-voltage characteristic was found in all oscillograms taken with the ignition system firing the engine. The magneto firing-voltage records obtained do not differ greatly for different engine test conditions. No significant differences in the breakdown voltages are observed in Figure 8. The restriking voltages which follow the breakdown are observed to be higher at higher speeds and greater engine power output.

A spark-plug voltage record is reproduced in Figure 9A. In this record the initial breakdown is not visible due to the extremely fast rise and fall. When a 15,000-ohm carbon resistor was installed in the high-voltage lead at the distributor, the breakdown voltage was observed as shown in Figure 9B. In this record the initial breakdown of the spark plug is clearly visible. The resistor serves to decrease the rate of rise of voltage on the spark plug.

Electronic Oscillograph

Oscillograms described in this report were obtained with an oscillograph of older design. A newly designed cathode-ray oscillograph[7] with complete operating accessories is pictured in Figure 10. New features which make it particularly valuable for ignition studies are

1. Provision for either stationary or rotating film recording.

2. Photoelectric means for exposing the rotating film for exactly one revolution, independent of speed of film rotation.

3. Enclosed and shielded electric circuits in removable panels with safety features.

4. Sweep circuit selector switches which enable a quick setting of sweeps from one microsecond to 20,000 microseconds.

The different operating circuits are built into the cabinet on removable panel assemblies. The high d-c beam voltage is supplied by a transformer and rectifier tubes with capacitor filter all built into the main cabinet. The combination of high writing speed with either short- or long-time recording makes this a useful instrument for studying ignition circuits.

Conclusions

Ignition currents and voltages are measured with a cathode-ray oscillograph. Typical oscillograms are shown which explain the operation of an ignition system used on a high-power aircraft engine. The importance of complete radio shielding and adequate electrical insulation becomes apparent with increased knowledge of ignition voltages and currents. Future ignition studies will be facilitated with a newly developed high-voltage cathode-ray oscillograph.

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Capacitor Stabilization of Arc-Welding Transformers

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SINCE THE PROCESS of metallic arc welding was discovered, some of this welding has been done with alternating current. The fact that a transformer, with no moving parts and its resultant simplicity, could be used always has made the use of alternating current for welding desirable. When only bare welding electrodes were available, it was necessary to have a welding transformer with the secondary voltage so high as to be dangerous to the operator. Even with this high open-circuit voltage, the arc with the bare electrode was so unstable that it was very difficult to maintain. Consequently, the transformer was never popular as a power source for welding until the bare welding electrodes had been replaced by the modern coated electrode.

Seven or eight years ago, the standard secondary voltage for welding transformers was approximately 110 volts. Improvements in the coatings of the electrodes used for a-c welding since have enabled us to reduce the standard open-circuit voltage of these welding transformers to between 70 and 80 volts. Some transformers which are expected to be used with a limited variety of electrodes have secondary voltages as low as 50 volts.

During this period of growth, the users of the a-c equipment for welding naturally have become aware of its advantages as a power source in comparison with the rotating machinery generally used as the d-c power source, but always have been somewhat dubious about the relative safety of the two systems. Experts in both types of welding can argue at great length on this subject, but experience seems to bear out the fact that lower open-circuit voltages must be used with the a-c systems if they are to have safety equivalent to the d-c system.

During these last few years, most of the companies manufacturing a-c welding transformers have supplied as an optional feature a no-load voltage-reducing apparatus consisting of the necessary contactors and relays to change the voltage at the electrode holder from the usual no-load value of 70 to 80 volts to a lower value of 25 to 35 volts. Of course there are those who properly might contend that even these voltages are not safe, and probably one must agree that the only safe voltage is zero.

One method of arriving at a desirable voltage for the a-c welding system would be to assume that the present-day d-c welding systems are safe, because very few accidents are reported on these d-c operations. Many of these d-c welding sets have maximum no-load voltages of 90 to 100 volts. It might be reasonable, therefore, to assume that any a-c system which had a peak voltage on the a-c sine wave no higher than the voltage of the d-c welding system would be equally safe. Using this reasoning, we can assume that a transformer with a secondary voltage of 70 volts is equivalent in safety to a d-c welder with a no-load voltage of 99 volts, and a transformer with 65 volts corresponds in safety to a d-c welder of 92 volts. This logic is not easily proved to be correct, and the writers do not contend that it is; but on the basis of this logic an attempt was made to develop a transformer for general purpose welding with a secondary voltage of 65 volts which would perform satisfactorily with all makes and varieties of a-c welding electrodes.

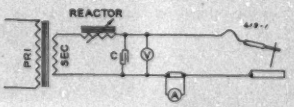

Figure 1. Circuit diagram

Investigation of the a-c welding arc with the magnetic and cathode-ray oscillograph indicated that capacitance in parallel with the arc produced a stabilizing effect because of the possible higher restriking voltages at current zero and because of the extra energy delivered to the arc immediately after restriking. Practical welding tests with capacitors connected as shown in Figure 1 bore out the results indicated by the oscillograph tests. It was then necessary to develop some means of determining the actual value of a particular amount of capacitance in reducing the required no-load voltage of the transformer. Our electrode development engineer, E. H. Turnock, suggested that welding tests with different transformer no-load voltages would indicate the degree of arc stability by the number of times the arc extinguished itself per electrode used. Tests therefore were conducted in which a number of electrodes were used at each of a number of transformer no-load voltages. The number of arc outages per electrode was recorded. These tests gave a reasonably smooth curve, indicating a definite relationship between the number of the arc outages and the transformer voltage. By extending these curves to the zero axis of the arc outage scale, one can assume that with this particular kind of electrode and welding setup, the voltage indicated by the curve to give no arc outages will be the minimum stable open-circuit voltage.

By running a series of such curves with various types and sizes of electrodes, one could determine the minimum open-circuit voltage which could be used for that variety of electrode. Similar curves also were taken with various values of capacitance connected across the transformer output terminals as shown in

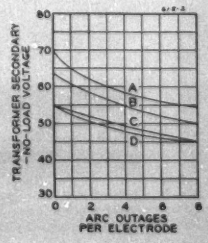

Figure 2(left). Stability curves for 1/16-by-18-inch class 6020 electrode

60 cycles, 180 amperes

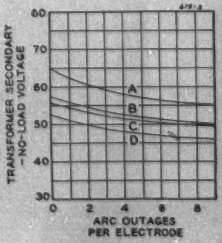

Figure 3(right). Stability curves for 1/4-by-14-inch class 6011 electrode

60 cycles, 105 ampere

Figures 2 and 3: *A*—No capacitor, *B*—60 microfarad, *C*—120 mircofarad, *D*—180 microfarad

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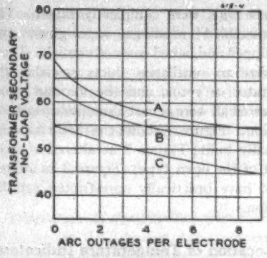


Figure 4. Stability curves showing effect of high lead reactance

$^{3}/_{16}$-by-18-inch class 6020 electrode, 60 cycles, 180 amperes

A—No capacitor
B—120-microfarad long leads
C—120-microfarad short leads

Figure 1. Figure 2 shows that for a given electrode, the addition of a 60-microfarad capacitor reduced the required secondary voltage from 70 volts to 63 volts, and a 120-microfarad capacitor allowed a reduction of the transformer secondary voltage to 55 volts. Figure 3 shows the results of similar tests on a different type of welding electrode.

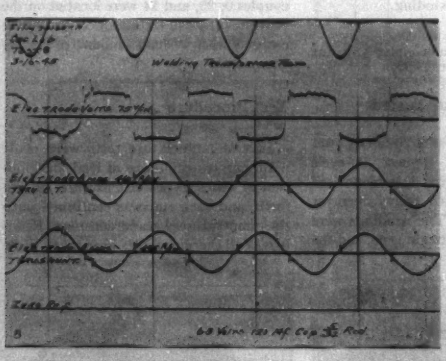
It was expected that the long leads sometimes used for welding would introduce a considerable reactance in the welding circuit between the arc and the capacitor and reduce the effectiveness of the capacitor as a stabilizer. In order properly to determine the effect of such leads, tests were conducted with the same transformer and capacitor arrangement with 200 feet of single conductor welding cable from each terminal to the welding position. These 200-foot leads were in one test laid out on a steel floor and, in another test, were arranged in coils on a steel floor. The latter arrangement proved to have twice as much reactance as the former, and the center curve in Figure 4 indicates the result of such a lead arrangement in reducing the stabilizing effect of the capacitor. This combination of 200-foot leads in coils gave a higher lead reactance than ever has been reported in actual practice, and this is considered to be an extreme condition.

In planning a line of welding transformers using this method of stabilization, the designer must compare the additional cost of the capacitor and its mounting with the reduced size of the transformer itself as well as the more abstract, but nevertheless desirable, improvement in safety. He also must allow sufficient margin in the use of the curves obtained by such tests to care for a reasonable length of welding leads and for a low primary voltage. The amount of margin included to care for these points is empirical and must be based on the designer's experience with these factors. One could assume, however, that a 120-microfarad capacitor and 65-volt transformer would give a reasonable margin of stability as indicated by the afore-mentioned curves.

Figure 5 shows a typical oscillograph record of the welding current and arc voltage with such a transformer–capacitor combination. Figure 6 shows a similar record without the capacitor. Visual observation of the cathode-ray oscillograph screen during welding with this capacitor stabilization indicated that the capacitor gave energy to the arc not only at the current zero point, but also occasionally within the half cycle of current flow when some arc disturbance seemed to require such energy.

The capacitor during any half cycle is charged with a certain amount of energy. When the voltage drops to zero, the capacitor tends to discharge. Figure 1 indicates that there are two possible paths for discharge of this stored energy. One of these paths is through the secondary winding of the welding transformer in series with the adjustable reactor. This combination offers a very high impedance in the form of reactance to the discharge of the capacitor energy. The other possible path is through the welding arc which is presumably an air gap at the time of current zero and therefore also offers high impedance in the form of resistance to the discharge of the capacitor. This causes the potential of the capacitor to build up very rapidly until it reaches a value that will break down the air gap. This reestablishes the welding arc at a lower transformer secondary voltage than would be the case without the high initial potential of the capacitor discharge. As current flows across the arc, the capacitor discharges. If the arc opens, the capacitor potential rises again, and the arc is reignited. Figure 5 shows that the discharge of the capacitor is oscillatory and shows that this discharge may occur at other times than the zero current point.

The net result is that a stable welding arc can be maintained at a lower transformer secondary open-circuit voltage with a capacitor across the arc than without the capacitor. It is the authors' opinion that capacitor stabilization can be used economically to improve simultaneously the performance and safety of welding transformers.



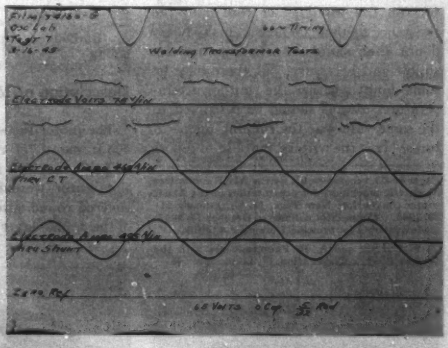


Figure 5 (left). Oscillogram of welding current and arc voltage with capacitor stabilization

Figure 6. Oscillogram of welding current and arc voltage without capacitor stabilization

Shutdown Versus Hot-Spot Temperatures in Polyphase Induction Motors

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THE "Test Code for Polyphase Induction Machines," AIEE Standard 500, paragraphs 50 to 58 inclusive, contains complete instructions for making temperature tests and reads in part as follows:

"The temperatures indicated by the thermometers placed on the motor at the start of the test usually rise when the motor is stopped. These values . . . . must be recorded. . . . . The highest temperature . . . . recorded will be taken as the actual temperature attained during the test."

The test code, therefore, requires that the temperature rise of a motor taken either while running, or at any time after shutdown, must not exceed the value stamped on the nameplate.

Readings are taken after shutdown in order to disclose abnormal temperatures which may not be detected by thermometers on the windings or core or by the resistance method. There seems to be no doubt that shutdown readings are desirable and necessary, but there may be some doubt whether the shutdown temperatures always should be restricted to the same values as the running temperatures. It is the writers' purpose to report the results of certain tests which were made to investigate this point and to recommend desirable changes in the test code and in ASA Standards.

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Scope of Tests

Temperature tests were made at various loads and frequencies on a motor having a protected frame; with openings cut in the frame to make it of the open type; and with very large openings giving practically unrestricted ventilation. Tests also were made with most of the openings closed to imitate a totally enclosed machine. Several rotors were tested having different resistances and load losses. The temperature rise of the stator windings was measured by three methods:

1. Surface thermocouples on the hottest accessible part of the winding.
2. Resistance.
3. Embedded thermocouples (using enough to locate the hot spot).

Description of Motor Tested

The motor tested was a 50-horsepower 405-frame 1,750-rpm 3-phase 60-cycle 440-volt machine having a semienclosed slot stator wound with heavy formvar covered round wire. The windings were of the double-layer diamond type, and the free ends were completely taped. The assembled windings were given two dipped and baked coats of varnish. There were no ventilating ducts in either the stator or rotor, and the various rotors tested all were of cast aluminum construction. Figure 1 shows the motor as originally built; Figure 2 as altered to make it of the open type; Figure 3 as altered to have practically unrestricted ventilation.

Location of Temperature Indicators

Sixteen thermocouples were located inside of the windings as shown in Figure 4. Thermocouples 17, 18, 19, and 20 were silk taped inside the loops of the coils just inside the tape which covered the free ends. Thermocouples 6, 8, 10, 12, 14, and 16 were silk taped to the coils inside the slot next to the 0.025-inch insulation separating the winding from the wooden wedge. Thermocouples 5, 7, 9, 11, 13, and 15 were silk taped to coil sides which lie in the bottom of the slot, just below the 0.060-inch insulation separating the coil sides. Thermocouples 1, 2, 3, 4, 21, and 22 were on the outside of the tape on the free ends, embedded in crevices in the windings, and covered with a small amount of sealing compound. Thermocouples 0, 23, and 24 were located on the outside surface of the stator core and were covered with a small amount of sealing compound.

Test Procedure

Several temperature tests were made with various conditions of load, distribution of losses, types of enclosure, and so forth, and each run was continued until the temperatures became constant. Readings of all thermocouples were taken while

Figure 1. Protected type squirrel-cage motor

Figure 2. Normal open type squirrel-cage motor

Figure 3. Exaggerated open type squirrel-cage motor

the motor was running. Readings of all thermocouples, resistance, and rotor temperatures were taken at frequent intervals after the motor was shut down to determine how the heat was redistributed. These readings were continued until well after all of them had reached their maximum.

Results

Fifteen sets of observations were made to determine the behavior of the temperatures of various parts after shutdown, and five of them are plotted in Figures 5, 6, 7, 8, and 9. The conditions of test are given in Table I.

These graphs show the behavior of the temperatures after shutdown at the hottest part of the core and the copper available to surface thermocouples, the hot spot as located by embedded thermocouple, and the rotor. The temperature rise by resistance also is plotted.

Table I. Test Conditions

Figure	Frame	Rotor
5	Totally enclosed	Low resistance
6	Protected	High resistance
7	Protected	Low resistance
8	Normal open	Low resistance
9	Exaggerated open	Low resistance

Table II. Hot-Spot and Maximum Shutdown Temperatures

Figure	Frame	Temperature Rise: Shutdown	Temperature Rise: Hot Spot	Shutdown in Per Cent of Hot-Spot Temperature Rise*
5	Totally enclosed	50	50.6	98.8
6	Protected	61.9	60.7	88.8
7	Protected	47.5	54.5	87.2
8	Normal open	39.0	46.4	84.0
9	Exaggerated open	38.5	48.6	79.2

* The shutdown figures are the maximum values taken by thermocouples located on the hottest part of the windings or core accessible to thermocouples.

Table III. Temperature Data for Open-Type A-C Motors

Horsepower	Table	Number of Tests	Shutdown in Per Cent of Hot-Spot Temperature Rise*
Integral	II	5	88 to 91
		1	77
Integral	IV	4	91.1 to 95.5
Fractional	I	2	92 to 95
Fractional	II	10	86.5 to 95.3
Fractional	IV	8	89 to 98
Fractional	VI	6	94 to 97
Fractional	VII	16	92 to 102

* The shutdown figures are the maximum values taken by thermocouples located on the hottest part of the windings or core accessible to thermocouples.

The hot-spot temperatures and maximum shutdown temperatures taken from these graphs are given in Table II.

Two papers published in 1945[1,2] contain data taken from temperature tests made by ten different observers, and the

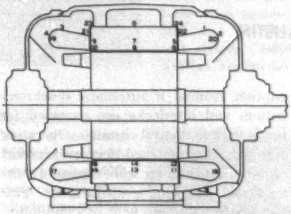

Figure 4. Location of thermocouples

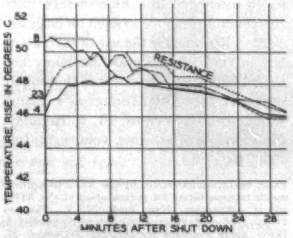

Figure 5. Behavior of temperatures, totally enclosed squirrel-cage motor

Line 8—Hot spot
Line 23—Core
Line 4—Winding surface

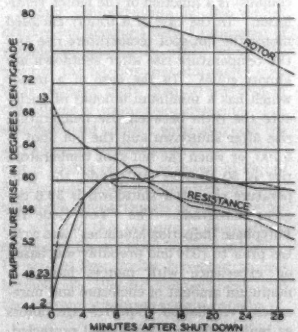

Figure 6. Behavior of temperatures, protected type squirrel-cage motor

Line 13—Hot spot
Line 23—Core
Line 2—Winding surface

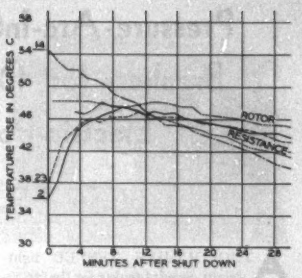

Figure 7. Behavior of temperatures, protected type squirrel-cage motor

Line 14—Hot spot
Line 23—Core
Line 2—Winding surface

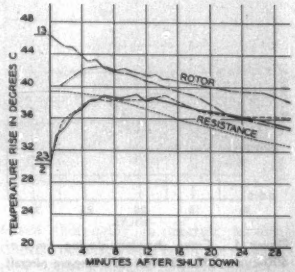

Figure 8. Behavior of temperatures, normal open type squirrel-cage motor

Line 13—Hot spot
Line 23—Core
Line 2—Winding surface

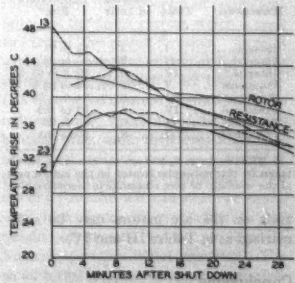

Figure 9. Behavior of temperatures, exaggerated open type squirrel-cage motor

Line 13—Hot spot
Line 23—Core
Line 2—Winding surface

Pressure-Arc-Interruption Circuit Breakers for 400-Cycle Aircraft Electric-Power System

B. O. AUSTIN
MEMBER AIEE

A THOROUGHLY TESTED light-weight circuit breaker for the 208Y–120-volt 3-phase 400-cycle a-c system for large aircraft is now a reality. The circuit breaker is electrically operated, remotely controlled, with latched-in main contacts. The design is suitable for paralleling generators and busses, circuit interruption, manual or automatic synchronization, and interlocks are provided for use in various control circuits. Operating solenoids are designed for low current requirements and for wide ranges of voltages and ambient temperatures. Size and weight have been kept to a minimum.

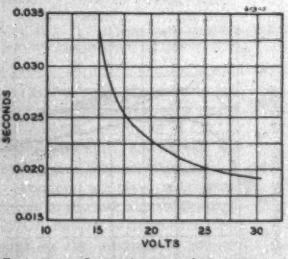

Figure 1. Curve showing closing time of 400-cycle 208–120-volt 120-ampere aircraft circuit breaker at various applied voltages

General Considerations

The Army Air Forces has become very much interested in a high-voltage high-frequency 3-phase a-c system for large aircraft. Reasons for the use of such a system in very large aircraft are many and varied and have been covered thoroughly elsewhere. ("Why Tomorrow's Planes Will Have A-C Systems," T. B. Holliday. *Electrical Manufacturing*, volume 32, July 1943, page 88.)

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Circuit breakers for this system must perform under extreme variations in environment. Satisfactory performance has been proved in altitude chambers up to and including 55,000 feet, the limitations being in test equipment and not in the circuit breaker. It operates satisfactorily from −70 degrees centigrade to +60 degrees centigrade. The circuit breaker continues to function properly after being subjected to a relative humidity of 95 to 100 per cent at a temperature of approximately +40 degrees centigrade for a period of 30 days. Vibration encountered in aircraft does not affect the operation of the circuit breaker. One vibration test passed by this circuit breaker consisted of subjection to vibration for a period of more than three hours in each of the three planes of operation; the vibration consists of a simple harmonic motion having a total excursion of 1/16 inch and a frequency varied uniformly between 10 and 55 cycles per second. The circuit breaker

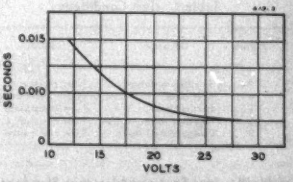


Figure 2. Curve showing opening time of 400-cycle 208–120-volt 120-ampere aircraft circuit breaker at various applied voltages

Table IV. Temperature Data on Plain Enclosed Type A-C Motors

Horsepower	Table	Number of Tests	Shutdown in Per Cent of Hot-Spot Temperature Rise*
Integral	I	2	93 to 95
Integral	II	3	95 to 98
Integral	IV	5	92.3 to 95.9
Fractional	I	2	92 to 98.5
Fractional	III	8	91.2 to 98.2
Fractional	IV	8	95 to 100
Fractional	VI	6	95 to 98
Fractional	VII	8	96 to 101

* The shutdown figures are the maximum values taken by thermocouples located on the hottest part of the windings or core accessible to thermocouples.

tests on the a-c motors may be summarized as in Tables III and IV.

Conclusions

From these tests it may be concluded that the relation between hot-spot temperature rise and the temperature rise after shutdown (taken by thermocouples which are located on the hottest part of the windings or core accessible to thermocouples) is a function of the motor ventilation. In the case of a totally enclosed motor the hot-spot temperature rise and the temperature rise after shutdown are almost equal. In the case of a motor which has a minimum amount of enclosure the ratio between the temperature rise after shutdown and the hot spot is 0.792, or when the hot-spot temperature rise is 50 degrees centigrade, the temperature rise after shutdown is 39.6 degrees centigrade. The "Test Code for Polyphase Induction Machines" was written prior to 1934 and probably was based on experience with motors having a minimum amount of enclosure and unrestricted ventilation. Squirrel-cage motors as built today are fairly well protected, and it would seem perfectly fair to conclude that the shutdown temperature rise in these motors is about 90 per cent of the hot-spot temperature rise, which would allow a shutdown temperature rise of 45 degrees centigrade instead of the 40 degrees centigrade figure now required.

Recommendations

In view of the fact that the trend is toward protected motors, it is recommended that the "Test Code for Polyphase Induction Machines AIEE 500" and the "American Standard Rotating Electrical Machinery C-50" be modified to allow a temperature rise after shutdown of 45 degrees centigrade on protected type motors having a nameplate temperature rating of 40 degrees centigrade.

References

1. INVESTIGATION OF HOT-SPOT TEMPERATURES IN INTEGRAL-HORSEPOWER MOTORS. L. E. Hildebrand, B. M. Cain, F. D. Phillips, W. R. Hough, J. G. Rosswog, C. P. Potter. AIEE TRANSACTIONS, volume 64, 1945, March section, pages 124–8.

2. INVESTIGATION OF HOT-SPOT TEMPERATURES IN FRACTIONAL-HORSEPOWER MOTORS. L. H. Hirsch, R. F. Munier, M. L. Schmidt, L. W. Wightman, F. S. Himebrook, T. C. Lloyd, O. G. Coffman, C. P. Potter. AIEE TRANSACTIONS, volume 64, 1945, March section, pages 129–38.

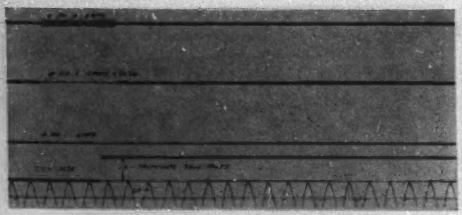


Figure 3. Oscillogram of a short circuit to neutral of a 3-phase system showing interrupting test phase number 2 at 400 cycles, 208 volts, pressure and temperature equivalent to 55,000-feet altitude (—40 degrees centigrade)

withstood a sand-laden air stream test for a period of five hours.

Obviously the most important single function a circuit breaker must perform is satisfactory interruption of current under all conditions of operation. High voltages at high altitudes are more difficult to handle when arc rupturing is involved. This is due to the decreased atmospheric pressure surrounding the arc when it is established. An effective method of controlling this difficulty is to design arc interrupters which are not subject to altitude conditions.

Pressurized Arc Interruption

The basic design problem in producing such a circuit breaker was the devising of a suitable structure which would deionize effectively the arc gases and thus interrupt high current and high voltages at altitude without damage. Several well-known means commonly are employed to cool and deionize the gases of the arc column, thereby producing an instability of the arc which results in its disappearance. They are

1. Lengthening of the arc column.
2. Air or gas blasts.
3. Surface deionization.
4. High gas pressure or vacuum.
5. Fluid action.
6. Multiple arc gaps.

One or more of these principles is employed in all circuit breakers.

This circuit breaker uses high gas pressure, surface deionization, and multiple arc gaps. The design is such that the circuit breaker has several operating advantages. With a self-pressurized arcing chamber the circuit breaker is independent of altitude conditions. Confinement of the arc to the self-pressurized chambers eliminates exposed flame which may contribute to fire. The simplicity of the arc-rupturing mechanism and the chambers makes possible a compact and light structure. Each of the 3-phase circuits are opened and closed by actuating the contact bridges located in the arc chambers. Each bridge bar is equipped with contacts

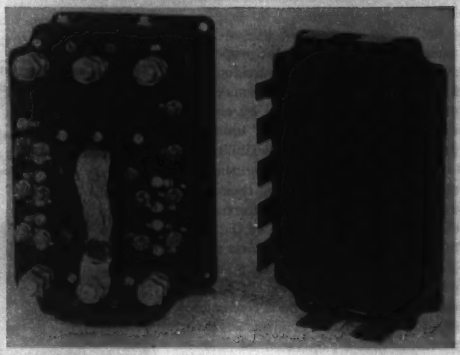


Figure 4 (upperright) View of complete 208Y–120-volt 120-ampere 3-phase 400-cycle remote electrically operated aircraft a-c circuit breaker

Figure 5. View of circuit breaker showing terminal cover removed

Note straps for changing interlock combinations at the control terminals, also note that the main leads enter at one end and leave at the opposite end

which engage or disengage two stationary contacts. In this manner double or multiple air gaps are provided. Pressurizing the arc to extinguish it quickly also makes possible having the contact mechanism operate through a short distance, thereby making possible higher magnetic forces in a small lightweight closing magnet and high opening speed.

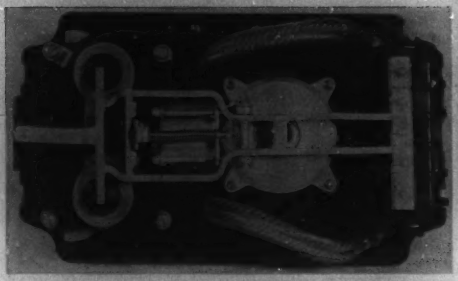
Arcing compartments of the circuit breaker are designed with a minimum of volumetric space. In other words the mass of the moving and stationary contacts occupies more than 50 per cent of the volume of arcing compartments. The side walls and contact parts also cool the arc, aiding in its disappearance. The circuit is broken rapidly as shown in Figure 3. Pressure which is built up in the semi-sealed-off compartments is generated by the arc, and this pressure is adequate to extinguish the arc at 55,000 feet or higher. It has not been found necessary to seal hermetically the arc compartment, and the pressure disappears fairly rapidly.

Construction

The contact mechanism is of the simple bridge type having two breaks per phase. Contact design is similar to that used on thousands of d-c contactors and has been tested thoroughly in aircraft service. Contact materials used are of the sintered type, using a mixture of silver and cadmium oxide which resist high vaporization thus limiting support to the continuity of the arc. Contact life exceeds 5,000 cycles of operation under rated load at 75 per cent power factor.

The latched mechanism used to hold the circuit breaker closed has the advantage of keeping the circuit energized, even though there is a temporary or permanent failure of the direct current which is used to control the circuit breaker. Springs with forces powerful in proportion to the masses to be accelerated are used to obtain high-speed contact separation. This reduces total operating time, reduces heating time, and, therefore, minimizes arcing and wear of contacts. Closing of the circuit breaker is accomplished by the use of a powerful solenoid which produces very high forces in proportion to the weight of masses to be accelerated. Manual operation is not provided. The small travel incident to use of pressurization permits a small magnet to develop the necessary high forces.

Six snap-action interlocks, vibration tested, are provided for use in the manual or automatic synchronizing control circuits, or in other control circuits where



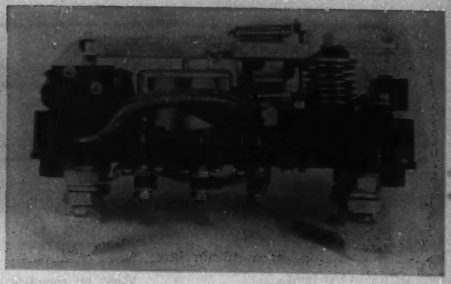


Figure 6. Plan view of circuit breaker showing closing tripping-magnet assemblies, also interlock and main contact operating lever

Figure 7 (above right). Elevation view of circuit breaker showing arrangement of internal parts

their use is necessary for the proper functioning of the controls. Individual interlocks can be made, either normally open or normally closed, simply by changing the position of the external links, thus providing the ultimate in flexibility.

One interlock operated by the main circuit breaker mechanism is in series with the operating coil and interrupts the closing coil circuit as soon as the circuit breaker is latched closed. Thus the coil is excited only during operation, and it is possible to make the solenoid assembly smaller than it would be if continuously rated. The latch mechanism is released by means of a d-c-operated solenoid.

The circuit breaker mechanism is enclosed with a seal which is sufficient to exclude dirt, water, or other foreign materials to a degree insuring operation under the most unfavorable conditions likely to be encountered.

Four mounting holes are provided, and the circuit breaker mechanism may be removed readily without disturbing the mounting or enclosure. Three main leads enter one end of this circuit breaker and leave the opposite end of the circuit breaker providing straight-through wiring. The control circuits enter from each side of the circuit breaker and at the same level as the main leads. Main and control terminals both are protected against accidental contact.

Operating Results

Speed of closing the main contacts of the circuit breaker from the time voltage is applied until the circuit is closed is very rapid. Figure 1 shows a voltage–time curve which gives actual operating speeds on closing as measured by oscillograph. The tripping or opening speed of the circuit breaker is shown in Figure 2. Operating speeds are well within the specifications of the Army Air Forces and assure proper functioning of the system under normal and fault operating conditions.

Figure 8. Exploded view of arc rupturing compartments showing contact assemblies

Closing coil and tripping coil are operated from the 28-volt d-c system which also is provided on the a-c-powered airplane, so that undesired operation will not occur during momentary faults.

Conclusions

This circuit breaker functions much the same as circuit breakers for industrial systems but weighs only a very small percentage of what a comparable industrial circuit breaker would.

Pressurized arc interruption is well adapted to circuit breaker performance under altitude conditions.

Effective sealing of the arc reduces the fire hazard present with open arcs.

Unusual high speed action during the closing and tripping periods has been obtained.

That operation is satisfactory under conditions of humidity, sand, dust, vibration, altitude, and acceleration normal to aircraft has been thoroughly proved.

It is handy for installation because the main lead arrangement is straight through and the control leads also are straight through at right angles to the main leads.

Lead terminals, both control and main, are shielded against accidental contact when this device is mounted in position.

Space requirements are small, and the device weighs only five pounds.

Design and test experience with this type of circuit breaker indicate that the same fundamental principles can be used for breakers having much higher ratings.

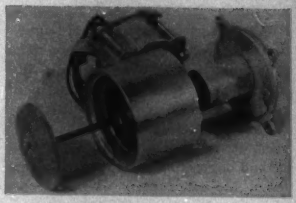


Figure 9. Exploded view of closing magnet assembly showing the component parts

Figure 10. View of moving-contact assembly showing springs and contact chambers

Transients in A-C Motors and Generators

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MEMBER AIEE

IN THE PAST, few electrical-engineering curricula have offered the undergraduate student more than the rudiments in the study of electric transients. Even today many engineering schools offer such courses only as graduate work. The result is that most engineering graduates confronted with such problems in connection with their work must acquire such information by self study and experience.

Many engineers in charge of the design, maintenance, or operation of large power systems of today are confronted with such problems as the choice, settings, or proper operation of such apparatus as circuit breakers, relays, and other protective equipment. Such equipment must operate adequately to protect the apparatus effectively and yet not cause undue interruption of service. Many such problems involve the conditions occurring during the transient period. Thus a clear conception of the nature of the changes during such periods is of great importance.

A great amount of valuable research work has been done in such studies, and a great deal of information is available.[1-8] Some of this material is in the nature of explanation or suggested methods of procedure, while some is in usable mathematical form, but most of the literature on such studies involves a great amount of detail and too often is written for those who already have a clear conception of the principles involved.

This paper proposes no mathematical study but does attempt to give a simple and clear conception of the variations that take place in the electric and magnetic circuits of a-c motors and generators and reactions between the armature and field, as well as reflected reactions between them during changes in operation. The analysis will be based upon well-known fundamental principles, and in some cases the results will be compared with mathematically derived results found in other papers as well as with actual oscillograms. This method of arriving at a physical conception of such transient conditions has been used quite successfully in introducing undergraduate students to the more advanced information available.

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Method of Analysis

In order to acquaint the reader with the method used in this analysis and also present a very brief review of a few rudiments of the study of electric transients for those who have not recently pursued such studies, a couple of simple transient cases will be analyzed.

First consider the sudden application of a direct voltage, E, to a simple series circuit consisting of a resistance, R, and inductance, L. Using Kirchhoff's voltage law, the algebraic summation of all the voltages involved in the closed loop must be equal to zero, which may be expressed thus:

$$Ri+Ldi/dt=E \qquad (1)$$

Solving this differential equation for the current flowing at any time after closing the switch, gives the result,

$$i=E/R-(E/R)\epsilon^{-Rt/L} \qquad (2)$$

In Figure 1, the oscillograph trace i shows this value at any time after the application of the voltage. If a horizontal line, I, is constructed at a distance above the zero line, equal to a current value of E/R to the same scale as the current i, it will be tangent to the oscillograph trace at a time when i attains its final steady-state value. Also let another curve, i', be constructed equal to $-(E/R)\epsilon^{-Rt/L}$ for the various values of t after closing the switch. The dashed decrement curve below the zero line will result. The sum of the ordinates of the two constructed curves at any time, t, always will give the ordinate of the oscillograph curve, i, for that time. This agrees with equation 2 which states that the actual current flowing in the circuit at any time after closing the switch is the sum of the final steady-state current and a hypothetical transient value.

Next consider that an alternating voltage of $E \sin(\omega t+\gamma)$ is applied to the same series circuit of resistance and inductance instead of the direct voltage E. Now the differential equation is

$$Ri+Ldi/dt=E\sin(\omega t+\gamma) \qquad (3)$$

and the solution for the instantaneous current, i, at any time, t, is

$$i=(E/Z)\sin(\omega t+\gamma-\theta)-(E/Z)\epsilon^{-Rt/L}\sin(\gamma-\theta) \qquad (4)$$

In Figure 2 the oscillograph trace, i, shows the actual current flowing at each instant. The constructed current wave, I, is equal to $E/Z \sin(\omega t+\gamma-\theta)$ or the current which would have been flowing in the circuit during the interval shown, had the switch been closed many cycles earlier. This coincides with i after steady-state conditions in the circuit are attained. The decrement curve, i', is a plot of $-(E/Z)\epsilon^{-Rt/L}\sin(\gamma-\theta)$. Here again equation 4, as well as the summation of the ordinates of the constructed curves, show that the actual current can be considered the final steady-state value plus the transient value.

The decaying transient value in each of these circuits varies as the logarithmic function of ϵ^{-x} where x in the cases mentioned was a function of time t. In Figure 3 a plot of ϵ^{-x} for varying values of x is shown and appears as a decimal factor, the value of which is unity at $x=0$ and drops to zero when x reaches infinity. It might be termed one of nature's laws of change which, in simple terms, says that the amount of decrease taking place at any time is always proportional to the magnitude at that time of the quantity changing. If the amount of change were at each instant added to the quantity changing, as in continually compounded interest, the logarithmic factor would be e^x and

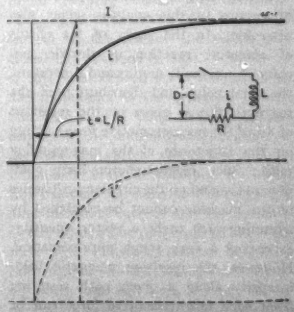


Figure 1. Building up a direct current in a circuit of resistance and inductance in series

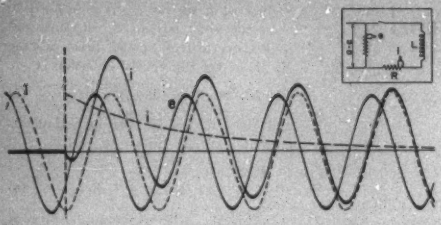


Figure 2. Building up an alternating current in a circuit of resistance and inductance in series

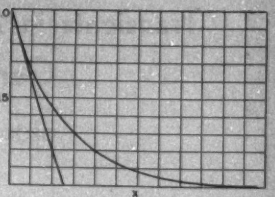


Figure 3. Decaying transient decrement curve

would start at unity when x is equal to zero and approach infinity as x approaches infinity. Other intermediate types of change factors might be such as $(\epsilon^x + \epsilon^{-x}) \div 2$ or cosh x, or $(\epsilon^{jx} - \epsilon^{-jx}) \div 2j$, or sin x, and so on.

The method of adding known components, illustrated by the two oscillograms, often proves to be a rather simple and fairly accurate method of arriving at the desired results and has been used quite extensively by Kurtz and Corcoran in their text on transient studies as one method of analyzing the transient conditions considered.

In the cases of the illustrations given, the circuit parameters were assumed constant. However, in electric machinery where magnetic materials are involved and in some circuits where the resistance or capacitance might vary for some possible reason, a mathematical determination of the components or the results in any other way is not easy. Such components or results sometimes can be determined by mathematical means, provided the law of the change involved is known; they may sometimes be determined by a series of very small but finite increments using relations known from experimental information; or they may be isolated from experimental determinations by the elimination of known components.

A final word of explanation in the use of vectors in this analysis seems also desirable. In the study of the effects of armature reaction in electric machinery, especially motors and generators, the final value and distribution of the magnetic flux is given by the resultant of all of the magnetomotive forces acting on the reluctance of the magnetic-flux path. Such magnetomotive-force components wound on the circular peripheries of the machine cannot be combined by assuming each to be a vector quantity, except as a very rough approximation. However, the resulting magnetic field-intensity along a given path resulting from each magnetomotive force can be considered more correctly a vector value. The magnetic flux caused by such a field intensity vector also can be considered a vector in the same direction, though not always proportional to the field intensity unless the permeability of the magnetic path remains constant.

Since the simplicity of this analysis depends to a large extent upon the use of vectors and since the method is not intended to be mathematically correct, the magnetomotive forces will be assumed to produce vector field intensities, and these in turn will be assumed to produce corresponding magnetic-flux vectors, which vectors will be combined in the usual manner. Where a change of permeability of importance must be taken into consideration, a gradual change in the length of the vector, according to the known law of change, will be assumed. Such assumptions will be pointed out at the time they are used.

Building Up the Rotating Magnetic Field of a Three-Phase Induction Motor

A three-phase induction motor stator (for simplicity assume a two-pole winding) connected to a suitable three-phase voltage supply has, after steady-state conditions have been attained, a single nonvarying rotating magnetic field produced by the varying combinations of magnetomotive forces of the three phases carrying the respective phase currents. In Figure 4a the three-phase windings $A_S A_F$, $B_S B_F$, $C_S C_F$, each is represented by a single turn in the proper angular position with respect to the polarity of the voltage applied or the direction of the current flowing in the coil at some definite instant of time. The subscript S indicates start and F finish of coil. Assume the phase currents shown in Figure 4b are flowing in the respective coils. The directions of the currents in the coils at a time indicated by the ordinate at t = zero time are identified by the usual plus and dot signs in the conductors. The resulting magnetomotive force of each phase will produce vector values of field intensities (not indicated) which would combine to produce the resultant field intensity H_R. For any time later H_R can be proved to remain constant in value but to rotate counterclockwise in synchronism with the supply. This vector will be called the final steady-state field intensity and will produce the final steady-state magnetic field ϕ_R shown in Figure 5a. This field flux also rotates at synchronous speed in the same direction.

Thus far the assumption has been made that the voltage had been applied at some earlier time. Now assume that the switch is closed at the time indicated by the ordinate t = zero. Since the circuit is inductive, all currents must start at zero, and similar to the case in Figure 2, the starting current in each phase will be the sum of the steady-state current in that phase plus a unidirectional decaying transient current. Both components are indicated in Figure 4b while the actual starting currents would appear

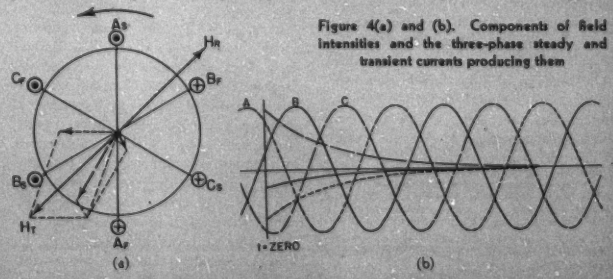


Figure 4(a) and (b). Components of field intensities and the three-phase steady and transient currents producing them

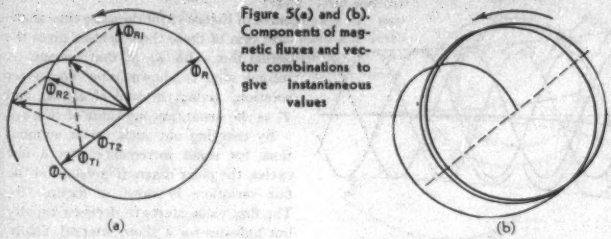


Figure 5(a) and (b). Components of magnetic fluxes and vector combinations to give instantaneous values

similar to the starting currents shown in Figure 7.

Likewise the magnetic field must start from zero and also can be assumed to be made up of the steady-state value ϕ_R, already explained, plus a component due to the combination of the magnetomotive forces set up by the transient currents in their respective coils.

In Figure 4a the corresponding instantaneous vector intensity for each of these transient currents at t=zero is shown in its proper directions and magnitudes, and their vector sum is H_T, which is equal in magnitude but reversed in direction to the rotating vector H_R. In Figure 5a the corresponding vector ϕ_T is indicated. The sum of ϕ_T and ϕ_R is zero at time t=zero, as it should be. Unlike the vectors H_R and ϕ_R which rotate, the transient vector H_T and corresponding flux ϕ_T remain stationary in space, since they are produced by unidirectional currents flowing in stationary coils. However, they decrease toward zero as time goes on in accordance with the decrement currents which cause them.

At any time after t=zero the actual magnetic field ϕ can be found by adding ϕ_R, which is in a new angular position, to the remaining value of ϕ_T. Such vector additions are shown in Figure 5a for angular positions of ϕ_R at 45 degrees and 90 degrees from the starting position.

By carrying out such vector additions at small angular increments for a few cycles of the alternating current, the value of ϕ becomes alternately greater and less than the final steady-state value but rapidly approaches a steady value as time goes on. The envelope thus derived is shown in Figure 5b, and the same values of ϕ plotted against time are shown in rectangular co-ordinates in Figure 6.

Figure 7 is an oscillogram of the actual currents flowing in the three phases of the induction-motor stator when first excited. These should correspond quite closely to curves obtained by adding the steady-state and transient values for each phase current in Figure 4b. However, in Figure 7 the permeability changes in the iron probably have introduced some distortions not assumed in Figure 4a, and the resulting magnetic-field variations also would be slightly altered from those shown in Figure 5b and Figure 6.

Three-Phase Alternator or Synchronous-Motor Load Changes

Closely related to the changes just described for the three-phase induction motor are those occurring when some sudden alteration in load takes place in the operation of a three-phase alternator or synchronous motor. Such an alteration may be from no load or part load to a much greater load or even short circuit, or it may be the reverse from a high load to a lower one or to no load. Were the machine an alternator the type of load might be resistive, inductive, or capacitive. In all cases the inductive nature of the machine's internal impedance always must be present.

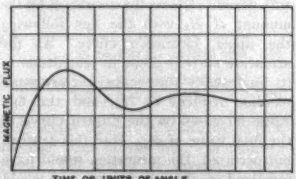


Figure 6. Variation in magnitude of magnetic field in rectangular co-ordinates

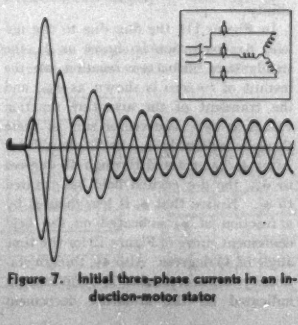


Figure 7. Initial three-phase currents in an induction-motor stator

To illustrate the method of analysis an alternator operating at no load suddenly will have a near short-circuit load applied to its terminals. For a clear conception of all the changes occurring the reader must rely on his knowledge of armature reaction in alternators, of the effects of the load power factor, and the effects of changes in the permeability in the magnetic circuit.

A two-pole three-phase alternator stator shown in Figure 8a, identical to the one used in discussing the induction motor, will be assumed. The only addition will be a two-pole d-c-excited rotor operating at some given speed. Again the three-phase steady-state currents are shown in Figure 8b. If the load switch had been closed at the time indicated as t=0, the transient component shown for each phase is also necessary. At this point, however, a radical difference from the previous case occurs. The alternator, rotating at a constant speed and with its d-c-excited field, is generating a rather high no-load voltage, while the final sustained current shown is caused by a greatly reduced voltage in comparison, since armature reaction and permeability changes have greatly reduced the magnetic flux of the field. Thus the so-called steady-state component of current flowing in each phase at the instant of closing the switch is somewhat greater than the final sustained value, and these components would be more in the order of those shown only as tips of waves in Figure 8b. As armature reaction reduces the field flux, these currents also will drop off to the final steady-state current values.

In each phase the final sustained value of current is assumed as one component, as was done in the case of the induction motor. A second is the usual unidirectional decaying current with an initial value equal to the value of the sustained current at the instant the switch was closed but reversed in sign. The decay of this must depend upon the resistance and inductance of the armature circuit. Since the sum of these two will not account for the unusually high values at the time the switch was closed, a third component must be present. Evidently this must be the difference between the final sustained current and the so-called steady-state value indicated by only the wave tips. This component will be a full-frequency oscillating current, decaying with time and with a decay factor depending upon the rate of change in the field flux, thus is controlled by the re-

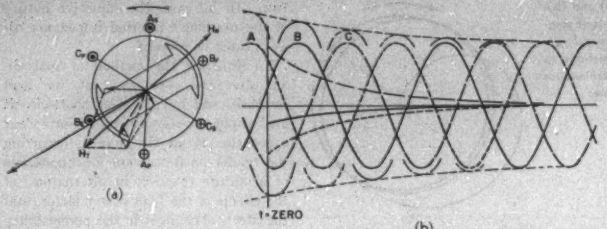


Figure 8(a) and (b). Components of field intensities and the three-phase steady and transient currents producing them

sistance and inductance of the field circuit. This has not been shown as an isolated component in the drawing.

The field-intensity components are shown in Figure 8a. The d-c field current at no load produces a field intensity of H_o. The final rotating field intensity, H_R, is the armature reaction arising from the sustained currents in the three phases. The transient intensity, H_T is due to the unidirectional currents of the three phases. As there is still another component in each phase of the armature which must have an armature reaction effect upon the field, it will rotate with the field similar to H_R but will decay to zero as the sustained armature currents are approached. This component will be accounted for by a decrease in the value of the flux generated primarily by the d-c field current.

Figure 9 is a typical equivalent single-phase vector diagram for the alternator showing the armature current and all the various voltages and voltage loss components, as well as the no-load field flux ϕ_o proportional to H_o, ϕ_R proportional to H_R, and ϕ_T proportional to H_T. The no-load voltage E_o is generated by ϕ_o. As explained in the discussion on the field-intensity components, a portion of the ϕ_o is lost because of the high initial armature currents and the resulting excess armature reaction. Reducing ϕ_o by the amount of this loss leaves ϕ_T the final steady-state flux due to the d-c excitation. This combines with the armature reaction flux ϕ_R to leave ϕ_G as the remaining flux to generate the internal generated voltage E_g, a part of which is lost in the winding impedance to leave E_T at the terminals. The final steady-state current is I which must be in phase with ϕ_R and the near short-circuit power-factor angle is θ.

To explain further the lost component of field flux, refer to the typical partial hysteresis loop, Figure 10, showing both increasing and decreasing field-excitation values. Assume the no-load condition to be at the maximum point with H_0 excitation due to the d-c field resulting in ϕ_o as the total flux. The initial armature current reduces the excitation by the amount of H_1 with the flux following the upper saturation curve. As the armature current drops in magnitude to its final steady-state value, the armature reaction reduces to H_R, and the flux value increases on the dashed curve to the final value of ϕ_0. Had this reversal not occurred, the saturation would have remained on the upper curve and would have been greater by the component of ϕ_L. Thus the flux ϕ_L equal to $\phi_o - \phi_T$ was lost due to the changes in permeability.

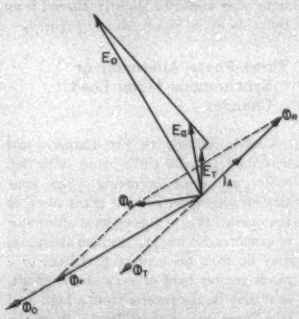


Figure 9. Equivalent single-phase alternator vector diagram

In Figure 11a the flux due to the no-load d-c excitation is shown as ϕ_o, the steady-state armature reaction at the instant of t=zero is shown as ϕ_{R0}, and the transient of the armature reaction values as ϕ_T. The vector sum of these three is evidently ϕ_o, as it should be. After ϕ_R has rotated through 45 degrees to ϕ_{R1}, the d-c excited field has rotated to ϕ_1. Notice that ϕ_1 is less than ϕ_o by a fraction of ϕ_L indicated on the field decrement curve of Figure 12 for the time angle of 45 degrees. Also ϕ_T, though stationary, has decreased to T_1 by an amount indicated on the armature decrement curve of Figure 12 for the same time angle. The sum of these three vectors gives the actual flux value ϕ_{R1} at that instant. A second step is shown after 90-degrees rotation, giving the sum of ϕ_{R2}, ϕ_2, and T_2 as the instantaneous value of flux ϕ_{R2}.

By carrying out such vector summations for small increments over a few cycles, the polar diagram envelope of the flux variations is shown in Figure 11b. The flux value starts to decrease rapidly but pulsates for a short interval, finally reducing to a steady rotating value of ϕ_G.

This varying flux is replotted in rectangular components in the graph A of Figure 13. In the graph B the various voltages acting in the d-c field coils are shown. Before the load is thrown on the alternator the direct voltage alone causes field current to flow. Just after throwing the load on, armature reaction causes a rapid decrease in the field flux ϕ_o, which change in flux induces a considerable voltage in the field coil. Because the flux value alternates, the induced voltage also alternates. The voltage is maximum when the flux is changing most rapidly and is zero when the flux is at a high or low point and not changing. The inductive nature of the field circuit will not allow the field current to change instantly, thus a transient component of voltage also must be present. This must have an initial value equal to the initial induced voltage but of the reverse polarity. The decrement factor of this transient voltage will depend upon the d-c field coil inductance and resistance.

When the ordinates of all of the components of voltage at each instant of time are added, the resulting curve is the actual voltage acting in the field circuit to cause current to flow. Thus the field

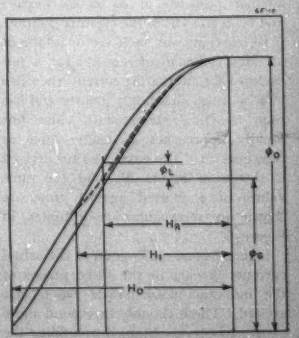
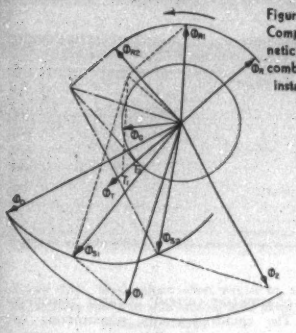


Figure 10. Typical partial hysteresis loop for alternator



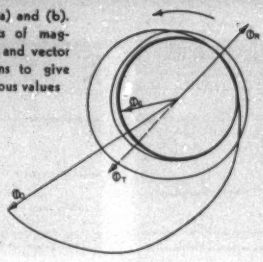


Figure 11(a) and (b). Components of magnetic fluxes and vector combinations to give instantaneous values

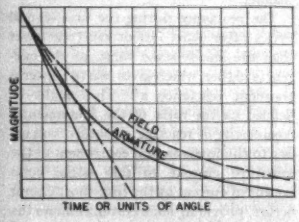


Figure 12. Armature and field decrement curves

current would be a similar curve, but lagging the voltage by some amount. A comparison of this constructed field-voltage curve with the field-current waves of oscillograms shown in Figures 14 and 15 shows the same characteristics.

The oscillogram in Figure 14 shows the voltage across one phase, the three-phase currents, the d-c field current, and the air-gap flux on a rotating-field type of alternator. Figure 15 shows the same values taken on a machine with stationary field poles and a rotating armature. This machine has a rather strong 11th harmonic due to armature slots.

The lower trace in all alternator oscillograms shows the actual value of the air-gap magnetic flux recorded by means of a bismuth-bridge type of magnetic-flux meter.[14–15] Using this with a stationary-pole type of alternator as in Figure 15 shows the rapid decrease of the flux due to armature reaction at the center of the pole face. On the leading tip the decrease is even more rapid, while on the trailing tip the flux often rises above the no-load value before it decreases, indicating flux distortion. In Figure 14 the increase in flux just after load is thrown on is caused by the position of the probe under a trailing pole tip at that instant.

Many attempts have been made to express mathematically the armature and field currents during such transient periods. Doherty and Nickle[6] give the following equations for the armature currents in phases *A*, *B*, and *C*:

$$i_A = \frac{e_0}{x_d}\cos(\omega t-\alpha)+e_0\frac{x_d-x_d'}{x_d x_d'}\times \epsilon^{-\sigma_f t}\cos(\omega t-\alpha)-e_0\frac{x_d'+x_q}{2x_d' x_q}\epsilon^{-\sigma_a t}\times \cos\alpha+e_0\frac{x_d'-x_q}{2x_d' x_q}\epsilon^{-\sigma_a t}\cos(2\omega t-\alpha) \quad (5)$$

i_B = same as phase A except for the use of $(\alpha+2\pi/3)$ instead of α (6)

i_C = same as phase A except for the use of $(\alpha+4\pi/3)$ instead of α (7)

Each phase current is made up of the algebraic sum of the four components shown. The first is the sustained value of current and corresponds to the sustained value of current in Figure 8b. The second is a full-frequency decaying current caused largely by the high no-load voltage, and decays as the armature reaction reduces the field flux to its final steady-state value. The coefficient of its decay factor σ_f depends upon the field-circuit constants. This component was accounted for by the loss of flux ϕ_L. The third factor is the unidirectional decrement corresponding to the decrement curves in Figure 8b. Its initial magnitude is equal to, but of the opposite polarity to, the instantaneous value of the sustained current corresponding to the point on the voltage wave at which the load switch was closed. The coefficient of its decay factor σ_a depends upon the circuit constants of the armature circuit. The fourth factor, which is usually not very large and is absent or nearly so in some types of generators is a double-frequency component, the decay of which depends upon the armature constants. No attempt was made to indicate this in Figure 8b. This component often appears in salient-pole types of machines which have no damper windings. There are possible sources for many small-scale variations other than those mentioned, as changes produced in the field by armature reaction will in turn cause altered generated voltages and currents in the armature. These in turn will further alter the field. There is no limit to the reflected effects back and forth between armature and field, but fortunately each succeeding reflection rapidly decreases toward zero.

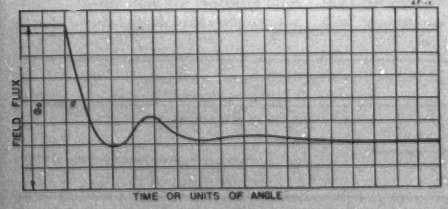
The same authors give the field-current equations as

$$i_f = e_0+e_0\frac{x_d-x_d'}{x_d'}\epsilon^{-\sigma_f t}-e_0\frac{x_d-x_d'}{x_d'}\epsilon^{-\sigma_a t}\cos\omega t \quad (8)$$

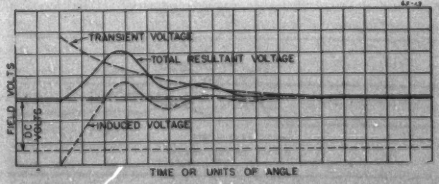
This equation might be altered thus

$$i_f = I_0+KI_e\epsilon^{-\sigma_f t}-KI_e\epsilon^{-\sigma_a t}\cos\omega t \quad (9)$$

where K is a constant depending upon the reactances involved. Here the three components are shown similar to the three components of voltage in Figure 13. The first is the current due to the direct voltage, the second is the unidirectional decaying component, the decay of which depends upon the field-circuit constants,



A



B

Figure 13. Magnetic-field variations and voltage components in field winding

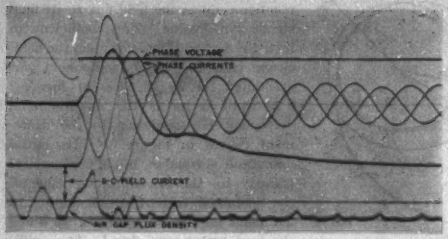


Figure 14 (left). Oscillogram of transients in an alternator with rotating field poles

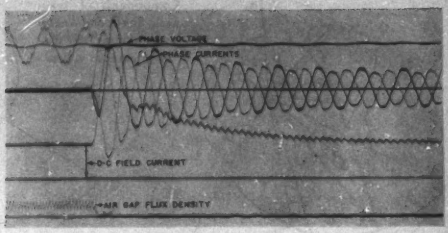


Figure 15. Oscillogram of transients in an alternator with stationary field poles

the third is the component due to the full-frequency alternating induced voltage, the decay of which depends upon the armature circuit constants.

Doherty and Nickle express all initial current components in terms of the no-load voltage e_n, assuming no saturation, and a percentage factor derived from the reactance acting, as the resistance of an alternator is usually so low its effect may be neglected in such factors. Thus the final steady-state current is the ideal no-load voltage e_n divided by the direct-axis component of synchronous reactance x_d.

A brief comment on the various reactances used in such mathematical studies might be of value here. In any circuit the current for a given voltage is limited by the impedance of the circuit. Each component of the impedance will absorb a proportional component of the total voltage, and the countervoltage of each reactance through which the current flows will just balance a corresponding component of the voltage applied. The reactance is then the ratio of that component of voltage to the current.

Referring to the armature current tracings in oscillograms such as Figures 7, 15, or 16, the impedance, or reactance if resistance is neglected, must continually vary from instant the switch is closed to the time when final steady-state conditions prevail, if the generated voltage is to be assumed constant. Since constant values of reactances are desired, certain limiting values are used. Further subdivisions of the reactances also are used. For example, synchronous reactance is a function of the armature current magnetomotive force, largely acting as armature reaction. At any given power factor of the load the armature magnetomotive force, which has been assumed to produce flux ϕ_g in Figure 9, might be considered as the resultant of two components, one acting on the axis of the main field, producing a demagnetizing action, the equivalent reactance of which is termed direct-axis synchronous reactance x_d, and the other acting at right angles to the main field, causing flux distortion of the main field, the equivalent reactance of which is termed quadrature-axis synchronous reactance x_q.

Thus the direct-axis synchronous reactance x_d for the balanced steady-state conditions might be defined as the ratio of the fundamental component of the reactive armature voltage, due to the fundamental direct-axis component of armature current, to this component of armature current, at rated frequency. The quadrature-axis synchronous reactance is defined in a very similar manner.

The reactance during the first several cycles after short circuit must be lower than the steady-state value, as the current is higher, which gives rise to the term transient reactance x'. This might be defined as the ratio of the fundamental component of reactive armature voltage due to the fundamental component of the armature current to this initial component of current at the time short circuit occurs, providing such current follows the normal decrement curve of the decreasing current. This initial value of current must be obtained by projecting the normal current transient back to the time of closing the switch. For most machines, and especially for those having damper windings on the rotor, the first two or three cycles do not follow the normal decrement curve but are abnormally high, though they decay rapidly down to the normal decrement values. For this portion of operation the reactance is still less and is accounted for by a subtransient reactance x''. This is the ratio of the generated voltage to the highest initial value of current which was produced at the instant of closing the switch. Such initial values are only the average of all three phases.

In practice both of these again are divided into the direct, x_d' and x_d'', and quadrature, x_q' and x_q'', values. All of these terms are defined in the AIEE "Standard Definitions of Electrical Terms" and may be determined by tests

Figure 16 (left). Oscillogram of transients in an alternator suddenly loaded with three-phase inductive load

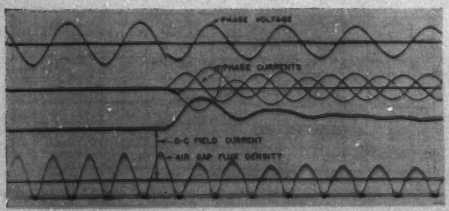
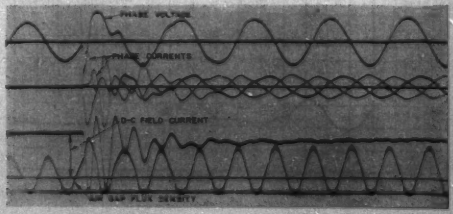


Figure 17. Oscillogram of transients in alternator suddenly loaded with a three-phase capacitive load



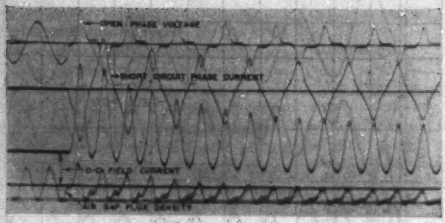


Figure 18. Single-phase short circuit on a three-phase alternator with rotating field poles, symmetrical type

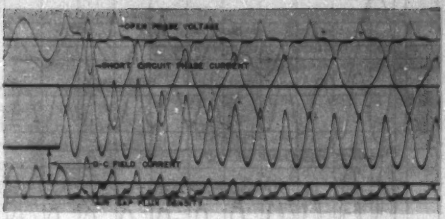


Figure 20. Single-phase short circuit on a three-phase alternator with rotating field poles asymmetrical type

or calculation, as proposed by various authors.[9–12]

Closely related to the reactance values in their importance during the transient period, are the decrement factors or their reciprocals, termed time constants T. In equation 2 the decrement factor is R/L, while the time constant is L/R and is a factor which gives an indication of the time required for the decreasing term to approach zero. In modern a-c machinery the reactance x which is a function of the inductance L purposely is made large either in the design of the machine or by introducing reactance in some part of the circuit, in order to limit the currents under short-circuit conditions. This can be done since the voltage regulator will maintain a constant voltage under steady conditions. The resulting large time constant causes the transient condition to persist for a considerable period after such changes, up to several seconds. The persistence of such high currents often may require higher settings on protective equipment than otherwise would be desired.

Many other transient conditions in alternators or synchronous motors might be analyzed in a similar manner. Two other oscillograms of such conditions are shown. Figure 16 shows the voltage, armature currents, field, and air-gap flux for the same alternator used for Figure 14, except that it is suddenly loaded with a highly inductive air-core inductance load. Here the inductance requires energy from the generator for a portion of the cycle and returns the energy the next half cycle. The resulting armature reaction in reducing the field, both during the transient period and after, is less than for the near short circuit. Figure 17 again is the same machine suddenly loaded with a capacity load. Here the capacity causes the current to lead the voltage, which gives a decided increase in the air-gap flux due to armature reaction.

Load Changes in a Single-Phase Alternator

The single-phase alternator proves quite interesting as a study of interrelated electric and magnetic fields, both under transient conditions as well as steady-state conditions. The theory is also important since faults often result in single-phase operation for their duration. The usual distortions in the voltage and current waves when using one phase of a three-phase alternator for careful tests may introduce considerable error in the results. The same is true for any single-phase alternator, unless it is specially designed to give a fair sine wave at all loads.

Such an alternator has the usual d-c excited field but has only one armature winding which usually does not use the whole periphery of the armature core. As the field rotates 180 electrical degrees for each half cycle, the armature reaction on the field always acts in the same direction, causing a continuous double-frequency pulsation in the field flux. When the load on such an alternator suddenly is changed or the alternator is short-circuited, two possible types of transient relations are possible. In the first, or symmetrical case, fairly perfect examples of which are shown by the oscillograms in Figures 18 and 19, the load switch was closed at a point on the voltage cycle at which, under steady-state conditions, the current value would have been zero, and the second, of which Figure 20 is a typical example, where the switch was thrown at a point on the voltage cycle where the steady-state current would not have been zero. This will be termed the asymmetrical case.

In making an analysis of these single-phase cases, certain assumptions again will be made which would alter the final general results only slightly. First the current waves will be assumed to be sine wave in shape, and second the effects of iron saturation will only be approximated.

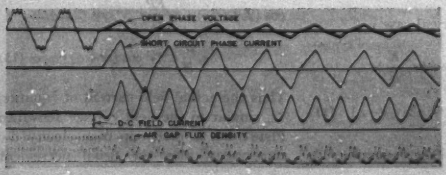


Figure 19. Single-phase short circuit on a three-phase alternator with stationary field poles, symmetrical type

Symmetrical Case

If the switch of a series resistance and inductance circuit is closed at a point on the voltage cycle when, under steady-state conditions, the current would have been zero, the usual inductive type of transient as in Figure 2 will not be present; the current will start at zero and continue at its final steady-state value. However, in the case of the single-phase alternator, as in the three-phase case, the no-load field flux and generated voltage are much higher than after the armature reaction has been able to reduce the strength of the field. Because the voltage is high at this first instant, the current also will be high but will drop as the armature reaction becomes effective in reducing the field. There then will be a decay of the armature current value but an equivalent decay will occur on both the positive and negative halves of the wave, and the resulting current will be symmetrical with respect to the zero.

Such a decaying alternating current in

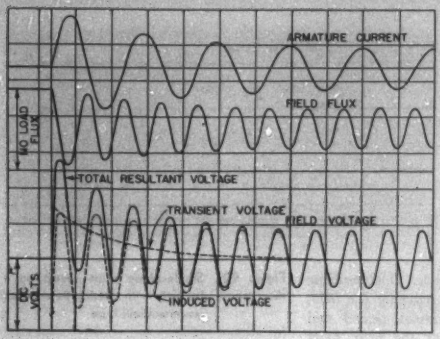


Figure 21. Armature and field components and their phase relations in a symmetrical single-phase alternator short circuit

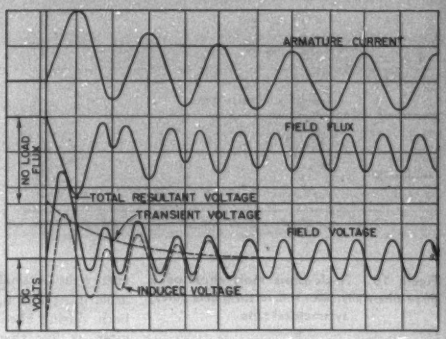


Figure 22. Armature and field components and their phase relations in an asymmetrical single-phase alternator short circuit

a single-phase alternator is shown as the top constructed curve in Figure 21. Since the d-c excited field, because of its rotation is always in a position to receive the same armature reaction effect for both polarities of the armature current, the magnitude of the flux will have two pulsations per cycle. If the usual short-circuit conditions are assumed the reaction will be to cause the flux to decrease most when the current is maximum, and the resulting field flux curve construction will be as shown by the second curve.

The variations in the field flux will generate a voltage in the d-c field winding of the same frequency and of a corresponding magnitude. This pulsating voltage is indicated as a dash curve in the lower set of curves. Since the field current and thus the field voltage must start at the no-load value and cannot jump instantly, the usual unidirectional decrement voltage, shown as a dash line, also must be present. The sum of the d-c, the pulsating, and unidirectional decrement components of voltage will give the actual voltage acting on the field circuit as shown by the full-line oscillation. This corresponds very well with the actual field current in oscillograms, Figures 18 and 19.

Asymmetrical Case

If the load switch is closed at a point on the voltage wave when, under steady-state conditions the current would not have been zero, then the type of transient shown in Figure 2 will be present. However, the effect of the high no-load voltage will amplify the magnitude of the current peaks, both positive and negative, just after closing the switch, but this excess current will die away to the final steady-state current after armature reaction has reduced the field flux to its final steady pulsating value. The upper curve in Figure 22 shows such an armature current curve. The second constructed curve is that of the resulting field flux because of armature reaction. In the lower set of field-circuit voltage curves, the pulsating induced voltage component due to the field-flux pulsations, and also the unidirectional decrement component, are shown in dash lines. Again the sum of these components, together with the direct voltage, gives the full-line curve as the actual voltage acting in the field circuit which corresponds well with the field current in oscillogram, Figure 20.

The induced voltage in the field circuit, as well as the current component resulting from this voltage, could have been further subdivided into a sustained pulsation at double-frequency component and a full armature-frequency pulsating component which decays with a decrement factor, depending upon the armature circuit constants.

Again Doherty and Nickle[5] have worked out quite complete and reasonably accurate equations for the armature field currents, as well as for the open-circuit voltage where a three-phase generator is supplying a single-phase load. For the armature current in the symmetrical case they give

$$i = 2ke_o \frac{K}{J} \sin \omega t + 2ke_o \frac{P}{J} \epsilon^{-\sigma' t} \sin \omega t \quad (10)$$

and for the asymmetrical case

$$i = 2ke_o \frac{1}{H} \epsilon^{-\sigma_a t} \cos \alpha - 2ke_o \frac{K}{H} \times \cos(\omega t + \alpha) - 2ke_o \frac{P}{H} \epsilon^{-\sigma' t} \cos(\omega t + \alpha) \quad (11)$$

In the symmetrical case, equation 10, the current is made up of the alternating sustained value plus an alternating value at the same frequency but decaying with a decrement factor depending upon the field-circuit constants. This second component is due to the high no-load field causing a high armature voltage and current at the instant of closing the load switch but dies away as armature reaction reduces the field. In the asymmetrical case, equation 11, the last two terms are components similar to those of equation 10. The additional first term is a unidirectional decaying component with a decrement factor depending upon the armature-circuit constants, with the initial magnitude depending upon the point on the voltage wave at which the load switch was closed. These components correspond very closely to the components necessary to give the armature currents assumed in Figures 21 and 22 respectively.

For the symmetrical case they give the field current as

$$i_f = e_o \frac{CK}{J} + e_o \frac{FP}{J} \epsilon^{-\sigma' t} - e_o \frac{FK}{J} \times \cos 2\omega t - e_o \frac{FP}{J} \epsilon^{-\sigma' t} \cos 2\omega t \quad (12)$$

and for the asymmetrical case

$$i_f = e_o \frac{CK}{H} + e_o \frac{CP}{H} \epsilon^{-\sigma' t} + e_o \frac{FK}{H} \times \cos(2\omega t + 2\alpha) + e_o \frac{FP}{H} \epsilon^{-\sigma' t} \cos(2\omega t + 2\alpha) - e_o \frac{G}{H} \epsilon^{-\sigma_a t} \cos(\omega t + \alpha) \cos \alpha \quad (13)$$

Thus the actual field current of equation 12, similar to the field voltage shown in Figure 21, is made up of a steady d-c component, plus the usual decrement

component, where a change in direct current takes place, plus a sustained double-armature-frequency pulsating component caused by armature reaction of the sustained armature current, plus a similar double-frequency component which decays with a decrement factor depending upon the field circuit constants. This component is the result of the decreasing armature current as it reduces to the final sustained value.

The field current of equation 13 similar to the field voltage of Figure 22 consists of four similar components plus a fifth decaying component, the decay of which depends upon the point on the voltage wave at which the load switch was closed. Notice that this is the full-frequency component before mentioned. All of the components in the equation are not shown as definitely separate components in Figures 21 and 22.

The constants in equations 10 to 13 are all rather involved factors made up of the various reactances of the machine and can be found in the original article; thus they will not be given here.

One additional observation might be mentioned. The voltage across the open-circuit phase in Figures 18, 19, and 20 are very distorted, and the phase current likewise is distorted. This is characteristic of single-phase loads on alternators not specially designed. The generated voltage is a function of the magnitude of the field flux and speed of rotation. If the magnetic flux is constant, the constant speed will generate a good sine wave shape of voltage. However, when the field flux is pulsating because of the single-phase armature reaction, at one instant the rate at which armature conductors are cutting flux is increased above that due to rotation by the increase in flux value and will generate a high peak of voltage, while at the next quarter cycle the flux is decreasing, which tends to decrease the total flux cutting action with the result that little or no voltage is generated at this time. Rather high voltage peaks may be the result, especially at the instant just after the load switch was closed.

Conclusion

No claim is made in offering more than a very approximate method of arriving at definite values in transient conditions of this nature. Other workers have covered quite adequately the more accurate mathematical phases. However, the analysis does attempt to offer a simple means of visualizing what to expect in such cases and of comparing the component parts thus visualized to the mathematical components derived by others. In short, the author has attempted first to offer a reasonably simple means of interpreting and visualizing the changes which result in such cases for the station operator or engineer who has little interest in knowing the magnitude of results and, second, to help acquaint the engineer who must deal with such magnitudes with the aid at his disposal, as well as to offer him a simple means of visualizing the components and reasons for components involved.

Nomenclature

R = total series resistance of the circuit in ohms

L = total inductance in circuit in henrys

e_o = no-load voltage generated by the alternator, assuming no saturation

x_d = three-phase line-to-neutral synchronous reactance on the direct axis

x_d' = three-phase line-to-neutral transient reactance on the direct axis

x_q = three-phase line-to-neutral synchronous reactance on the quadrature axis

x_q' = three-phase line-to-neutral transient reactance on the quadrature axis

$\omega = 2\pi f$, where f is normal frequency

ωt = angle in radians at time t

α = displacement angle between armature winding axis and axis of field pole at time of closing the switch

γ = angle between time of zero voltage and time of closing switch

θ = phase angle between current and voltage

i_A = current in phase A of alternator

i_B = current in phase B of alternator

i_C = current in phase C of alternator

i_f = current in d-c excited field winding of alternator

σ_a = decrement factor of armature circuit, a function of armature resistance and inductance

σ_f = decrement factor of field circuit, a function of field resistance and inductance

Other constants are explained in text.

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Lightning Performance of 220-Kv Transmission Lines—II

AN AIEE COMMITTEE REPORT

THE LIGHTNING performance of high-voltage transmission lines in the nominal 220-kv class was presented in a paper[1] before the Institute in 1935. That report presented data on the construction of these lines as well as their operating performance from a lightning viewpoint. There were then only ten companies operating transmission lines in the 220-kv class, and the significant data on all these companies' lines were reported.

The collection of data at one time and presentation in one place on the performance of these lines were of such interest and value in the transmission field that the committee recently was requested to bring the record up to date. Complying with this request, the committee is presenting this present paper. To obtain the data on which the present record is based, questionnaires were sent to 13 companies which were known to have lines built for operation in the 220-kv range, and replies were received from all 13 companies. The questionnaire, which was set up carefully by the lightning and insulator working group, comprised a total of 36 questions dealing with line construction, lightning outages, features used to improve lightning performance, and other features of the lines believed significant in studying and evaluating the lightning performance of the lines.

Purpose and Scope

The purpose of this report is, as just mentioned, to bring up to date the record of the lightning performance of lines in the 220-kv class. In presenting the data the lightning outage record, which was given on transmission lines reported in the previous paper,[1] has been continued to 1944 inclusive, and in one or two cases the major part of the record for 1945 is included. The record includes data from all companies in the United States and Canada known to be operating lines in the 220-kv class.

The plan of this paper is to present most of the data which are considered pertinent to the lightning record of the line and to comment on and compare in some cases the relative benefits of various factors which are known from experience and believed by theory to be conducive to better performing lines.

Another feature of value which it was expected would appear in replies to the questionnaire was any unusual means taken to improve lightning line performance and the benefits actually obtained. In addition to giving the outage record of the lines involved, the discussion presented herein gives the committee's evaluation of the effectiveness of different features of line construction. However, it is recognized that with so many variables influencing the lightning performance of lines of this type, opinion may differ as to the relative merits of different remedial measures which have been taken in actual line construction. Therefore, practically all of the data received from the contributors have been presented, so that anyone who chooses may study and analyze them in his own way.

Presentation of Data

Practically all the data which are considered pertinent to the subject at hand are included in Table I. In all cases the data are presented practically as submitted by the separate companies involved but may differ in minor features where the questions asked or the replies received were not wholly clear. Although the lines in this table are referred to as nominal 220-kv class, it should be pointed out that one (reference 2) operates at 190 kv and two (references 14 and 15) at 287.5 kv.

Paper 46-16, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE winter convention, New York, N. Y., January 21-25, 1946. Manuscript submitted November 16, 1945; made available for printing November 21, 1945.

This report was prepared by the lightning and insulator working group of the AIEE committee on power transmission and distribution. The personnel of the working group comprised: I. W. Gross, American Gas and Electric Service Corporation, New York, N. Y., *chairman*; H. A. Frey, Locke Insulator Corporation, Baltimore, Md.; W. W. Lewis, General Electric Company, Schenectady, N. Y.; J. T. Lusignan, Jr., Ohio Brass Company, Mansfield, Ohio; G. D. McCann, Westinghouse Electric Corporation, East Pittsburgh, Pa.; F. W. Packer, Pennsylvania Power and Light Company, Allentown, Pa.; Philip Sporn American Gas and Electric Service Corporation, New York, N. Y.; S. K. Waldorf, Pennsylvania Water and Power Company, Baltimore, Md.; E. R. Whitehead, Duquesne Light Company, Pittsburgh, Pa.

The committee expresses its appreciation to all 13 electric power companies for their prompt cooperation in supplying the records on which this paper is based, and also to G. D. Lippert for his efforts in compiling the data for analysis.

The extent of the 220-kv systems covered is shown in Table II, wherein it is shown that 13 companies are operating 35 lines totaling approximately 3,988 miles of line (right of way) and 6,601 miles of 3-phase circuit.

Discussion of Data

A brief summary and discussion of the outstanding features of line construction and line performance are presented. For convenience of analysis, however, some of the various factors which influence lightning performance have been segregated and discussed separately. It is realized that the effect of any one of these factors is so interlaced with that of the others, that it is not possible to evaluate definitely its influence from the insufficient data available.

Structural and Related Features

Location of Lines

The lines reported on are located in lightning territory which ranges from very light to heavy, the isokeraunic levels ranging from 5 in California to 45 in Illinois, but none being in the 70 to 90 range of the extreme southeastern section of the country. The isokeraunic levels shown in column 25 of Table I were taken from the United States Weather Bureau isokeraunic map.[3] The lightning severity, reported by each company is in column 24.

The average elevation of each line above sea level is given in column 21. These values range from 68 feet in California to 3,020 feet also in California. These figures are not considered particularly significant: first, because elevation above sea level in this range is not believed to have any appreciable influence on lightning frequency and severity; and secondly, because lines shown located in low average terrain may, and in some cases do, have part of their length in high-elevation country.

The types of country traversed by the lines (column 22) range from flat to rolling, hilly, and even mountainous. Most of the lines are in rolling to hilly country.

The average height of top conductor above ground (column 37) varies from 37 feet to 122 feet, the higher figure being on a 2-circuit line where right-of-way difficulties controlled. The more general range of top conductor elevation is from about 55 to 85 feet.

Towers, Conductors, and Overhead Ground Wires

Towers. The towers may be classified in three general types, as illustrated

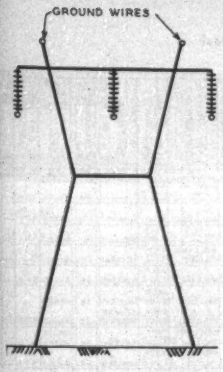

Figure 1 (left). Typical 220-kv single-circuit tower

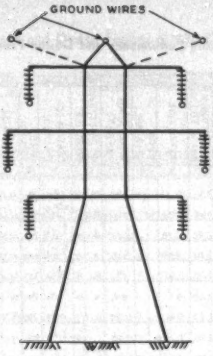

Figure 2. Typical 220-kv double-circuit tower

in Figures 1, 2, and 3. Figure 1 is a single-circuit line with conductors horizontally arranged. About 73 per cent of all the lines reported have this arrangement. Figure 2 is a double circuit structure with conductors vertically arranged. About 26 per cent of the lines have this arrangement. A part of only one line was arranged as in Figure 3, or about 1 per cent of the lines reported.

Line Conductors. The line conductors vary from 500,000 circular mils to 1,034,000 circular mils, with one line 1.4 inch in diameter. About 85 per cent of the lines have aluminum conductor steel reinforced conductors, and 15 per cent copper.

Overhead Ground Wires. About 14 per cent of the lines reported have no overhead ground wires, except that two lines have wires extending out one mile from the terminals. About 19 per cent have one overhead ground wire, and about 67 per cent have two overhead ground wires. The material is steel, aluminum conductor steel reinforced, Copperweld, and copper in the proportion of about 63 per cent, 16 per cent, 11 per cent, and 10 per cent respectively of the lines with overhead ground wires. The sizes vary for the steel wires from 3/8- to 3/4-inch diameter, for the aluminum conductor steel reinforced from 184,000 to 203,000 circular mils, for the Copperweld from 3/8- to 1/2-inch diameter, and for the copper from 2/0 to 4/0.

Insulation

Insulator Strings. In columns 12 and 13 of Table I are given the number of insulator disks and spacings between disks. The spacings vary from $4^3/_4$ to $6^1/_2$ inches. In order to place these on a comparable basis, so that published flashover data may be used, the suspension strings are reduced to equivalent number of units spaced $5^1/_4$ inches apart (column 59). It will be noted that these vary through a wide range, from approximately 10.6 to 18.4 units for lines operated at 220 to 240 kv, 8.4 to 12.3 units for lines operated at 190 to 200 kv, and 21 units for the 287-kv lines.

The critical flashover values of the insulator string[2] based on the 1.5x40 positive impulse wave are given in column 60.

Clearance to Structure. In column 57 is given the clearance to the tower with the conductor swung from the vertical to the angle given in column 58. These angles are 30 degrees, except in one case in which the angle is given as 45 degrees.

In column 61 are given the critical flashover values based on the 1.5x40 positive wave, assuming that the conductors are swung to the angle given in column 58. The rod gap values[3] are used to obtain the flashover values.

It is believed that under the wind and loading conditions prevailing in the lightning months, a 30-degree swing is ample to cover practically all cases.

Average Span

Average span lengths range from 590 feet to 1,320 feet or 9 to 4 towers per mile. The general average for all lines reported is in the order of 1,000 to 1,100 feet, or about 5 towers per mile.

Grading and Arcing Devices

The practice varies in the use of devices to grade the voltage on the insulator string or to take the arc on flashover. Some companies report using grading rings (column 26) or rings and horns, and others report horns only. In the light lightning severity territory of California, horns, or rings and horns, are used even for the early lines built between the years 1914 and 1923.

A number of companies report not using any grading or arcing devices, particularly where lines have been built in the last 15 years or so. It is suggested that the reason for the omission of these devices may be the high immunity from insulator and conductor damage experienced in service. This in turn possibly may be the result of faster clearing of faults over the insulator strings by high-speed circuit breakers or shortened relay time. It seems from the record that the use of grading shields and arcing devices on the newer lines generally is being abandoned.

Analysis of Lightning Performance

The three most important features of line construction that correlate most closely with actual lightning performance, although not necessarily in their order of importance, are thought to be:

1. **Use and location of overhead ground wires.**
2. **Insulation.**
3. **Tower footing resistance.**

Line Outages

The actual line outages are shown in column 54 for all lines. These have been reduced to a 100-mile-per-year basis in column 55 and to an isokeraunic level of 50 in column 56. On the 100-mile-per-year basis, actual outages vary from a high of 11.5 to a low of 0, with an average of about 2.30. The high figure of 11.5, references 7 and 7A, comprises the record of a line which initially was built and operated without ground wires and was located in a heavy lightning territory. It is interesting to note that this line, since protective features such as ground wires, counterpoises, and so forth, were installed, has a record for the past four years of 1.2 outages per 100 miles of line per year.

In case of 2-circuit lines, the single-line outages only usually are considerably

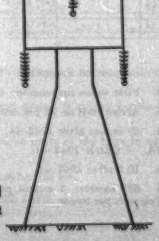

Figure 3. Special 220-kv single-circuit tower

Table I. Lightning Performance and Design Features of 220-Kv Lines

REF	NAME OF CO REPORTING	LINE DESIGNATION	DATE FIRST IN SERVICE	LENGTH OF LINE, R OF W MILES	NO OF CIRCUITS	TOWERS: CIRCUITS PER STRUCTURE	TOWERS: OPERATING KV, PHASE TO PHASE	TOWERS: NO PER LINE	TOWERS: TYPE (FIG NO.)	TOWERS: AVG. SPAN (FEET)	INSULATORS: NO PER STRING SUSP/D.E.	INSULATORS: SPACING (2) (INCHES)	CONDUCTORS: LINE: SIZE (MCM)	CONDUCTORS: LINE: MATERIAL	CONDUCTORS: LINE: NUMBER	CONDUCTORS: GW: SIZE (IN OR MCM)	CONDUCTORS: GW: MATERIAL	WIRE SAG: GW. ON AVG. SPAN (FEET)	WIRE SAG: COND. ON AVG. SPAN (FEET)	WIRE SAG: RISE, ELEV. ABOVE SEA LEVEL (FT)	TYPE OF COUNTRY	NATURE OF SOIL	LIGHTNING SEVERITY	ISOCERAUNIC LEVEL	INSUL. ARCING DEVICES: TYPE	INSUL. ARCING DEVICES: ARC DIST. (INCHES)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	NEW ENGLAND PWR SERV CO	FIFTEEN MILE FALLS - TEWKSBURY	9/30/50	26.4	2	1	231	1127	1	520	13/17	5¾	795	ACSR	2	1/2"	S	12	16	800	MOUNTAINS AND HILLS	ROCK CLAY SAND	—	24	RINGS	79 5
2	SHAWINIGAN WATER AND POWER CO	NO. 25-24	2/6/47	135.1	2	2	190	796	2	910	10/22	5¾	397	ACSR	2	7/16"	S	17	20	1000	HILLS ROLLING	GRAVEL	MODERATE	15	HORNS	(8) (4) 47 5
3	"	NO 31	1/28/50	108.1	1	1	240	538	1	1060	16/16	5 5/8	795	ACSR	2	7/16"	S	24	29	600	HILLS ROLLING FLAT	ROCK SAND	MODERATE	15	NONE	—
4	"	NO 35	11/1/48	14.3	1	1	200	388	1	1010	14/16	5 5/8	605	ACSR	2	7/16"	S	25	25	200	ROLLING FLAT	ROCK CLAY SAND	MODERATE	15	NONE	—
5	PHILADELPHIA ELECTRIC CO	CONOWINGO-PLYMOUTH MEETING	3/5/28	57.7	2	1	220	261	1	1170	16/18	5¾	795	ACSR	2	184	ACSR	29.2	34.8	360	ROLLING	ROCK CLAY	MODERATE	35	RINGS	83 3
6 6A	PENNSYLVANIA PWR & LIGHT CO	PLYMOUTH MEETING-SIEGFRIED	2/18/28	99	1	1	220	57	1	916	16/18	5¾	795	ACSR	2	184	ACSR	18.4	21.9	300	ROLLING FLAT ROLLING	ROCK CLAY	MODERATE SEVERE MODERATE	35	NONE	—
			2/18/28	38.8	1	1	220	186	1	1100	16/18	5¾	795	ACSR	2	184	ACSR	29.0	43.0	500		ROCK CLAY		35	RINGS	82 3
7 7A	PUBLIC SERV ELEC & GAS CO	SIEGFRIED-ROSELAND	4/11/26	66.7	1	1	220	317	1	1100	14-16/16 16-18/16	5¾	795	ACSR	(2) 2	184 ¾" CW	ACSR	18.5	51.5	1000	MOUNTAINS ROLLING MOUNTAINS	ROCK CLAY SAND ROCK	SEVERE	35	SINGLE HORNS	72 0
		SIEGFRIED-ROSELAND	4/8/32	41.8	1	1	220	211	1	1150	18-20	5¾	795	ACSR	2	203	ACSR	32.9	35.8	780	HILLS	CLAY	MODERATE	35	RINGS	83 9
8 8A	PHILADELPHIA ELECTRIC CO	PLYMOUTH MEETING-ROSELAND	8/9/30	46.2	1	1	220	239	1	1040	16/18	6	795	ACSR	2	203	ACSR	27.0	29.4	205	ROLLING FLAT	CLAY SAND ROCK	MODERATE	33	RINGS GRADE SHIELD	85 3 83 3
			8/9/30	29.6	1	1	220	145	1	1080	16/18	5¾	795	ACSR	2	203	ACSR	26.0	29.4	335	ROLLING	CLAY	MODERATE	35		
9	PENNSYLVANIA WATER & PWR CO	SAFE HARBOR-RIVERSIDE	10/1/37	50.0	1	1	220	281	1	940	20/20	5¾ 5¾	795	ACSR	2	3/8"	CW	17.1	26.3	330	ROLLING	ROCK CLAY SAND	SEVERE	36	NONE	—
10	"	SAFE HARBOR - TAKOMA TAP - WESTPORT	12/6/39	92.0	1	1	220	477	1	1020	20/20	5¾ 5¾	795	ACSR	2	203	ACSR	21.5	26.5	475	ROLLING	ROCK CLAY SAND	SEVERE	36	NONE	—
11	COMMONWEALTH EDISON CO	CORDOVA-CHICAGO	12/8/28	147.6	2	2	240	761	2	1020	18/20	5¾	900	ACSR	2	1/2"	CW	52.0 / 26.8	44.6 / 29.6	650	ROLLING FLAT	MOSTLY CLAY	—	45	NONE	—
12	BONNEVILLE PWR ADMINISTRATION	COVINGTON-COULEE NO 1	7/6/42	183.0	1	1	230	850	1	1140	16/18	5¾ (6)	795	ACSR	(7)	—	—	—	34	2500	MOUNTAINS TO FLAT	ROCK CLAY SAND	MODERATE	8	—	—
13	"	COULEE-SPOKANE 3&4	3/15/43	82.8	2	2	230	422	2	1035	16/18	5¾	795	ACSR	(7)	—	—	33.5	51.5	2000	HILLY TO FLAT	ROCK CLAY SAND	MODERATE	8	(9)	40
14	CITY OF LOS ANGELES	BOULDER DAM-LOS ANGELES 1&2	10/1/35	263.5	2	1&2	287.5 (288)	2493	1&2	750 970	24/22	5/6	14"	CU	2	7/16"	CW	31.8 (31.8)	45.8 (45.8) 236	2400	MOUNTAINS TO FLAT	ROCK CLAY SAND	MODERATE LIGHT	15	HORNS	110
15	"	BOULDER DAM-LOS ANGELES 3	5/5/40	263.5	1	1	287.5	1428	1	970	24/22	5/6	1.4"	CU	2	1/2"	S	37.8	45.8	2400	MOUNTAINS TO FLAT	ROCK CLAY SAND	MODERATE LIGHT	15	HORNS	110
16 16A	PACIFIC GAS & ELECTRIC CO	PITT LINES NO 1&2, HORIZ CONFIG SECT (163) PITT LINES NO 1&2, VERT CONFIG SECT (82)	4/1/23	83	2	1	230	—	1	720 (118)	13/12	5	518	ACSR	0	—	—	—	17	2000	HILLS ROLLING TO FLAT	VARIOUS	LIGHT	5	HORNS HORN OR SHIELD	71
			4/1/23	21.4	2 (1)	1 (1)	230	—	2	—	13/12	5 1/2	500	CU	0	—	—	—	24	200		CLAY	LIGHT	5		71
17 17A	"	TIGER CREEK-NEWARK, HORIZ CONFIG SECT TIGER CREEK-NEWARK, VERT CONFIG SECT	6/1/31	93	2	2	230	—	2	—	13/13 (13)	5½	518	ACSR	0	—	—	—	24	2500	MOUNTAINS HILLS TO FLAT	VARIOUS ROCK CLAY	LIGHT LIGHT	5	DISC SHIELD DISC SHIELD	71 5 71 5
18 18A 18B	"	BUCKS CREEK-BELLOTA (238) NOR'S CREEK-BELLOTA SECT (1924) BUCKS CREEK-BELLOTA DOUBLE-BELLOTA SECT (1944) BUCKS CREEK-BELLOTA BELLOTA-HEARDON 1&2	6/1/31	33	1	1	230	—	3	—	14/16	5 5/8 5 7/16 5 5/8	795 500	ACSR CU	0	—	—	—	17.5	1000	MOUNTAINS ROLLING TO FLAT ROLLING TO FLAT	ROCK SAND	LIGHT	5	DISC SHIELD DISC SHIELD	80 5 77 77
			11/1/44	11.0	1	1	230	—	2	—	14/16		795	ACSR	0	—	—	—	24	150		VARIOUS CLAY	LIGHT	5		
			6/1/31	10.2	2	2	230	—	2	—	14/16		795	ACSR	0	—	—	—	24	150		VARIOUS	LIGHT	5		77
19	METROPOLITAN WATER DIST OF SO CAL	BOULDER	11/1/38	23.1	1	1	230	94.5	1	1320	13/13	5¾	795	ACSR	2	(2nd) 1/2"	S	24	35	2000	HILLY TO FLAT	MOSTLY CLAY	MODERATE	15	NONE	—
20 20A	HYDRO-ELECTRIC PWR COMMISSION OF ONTARIO	QUEENSTON-BEAMSVILLE SECT (1951) DUNDAS-CHATSWORTH SECT (1952) BEAMSVILLE-LESAGE SECT (1951) LESAGE-PARRY SOUND TAPS, MAGNETAWAN TAPS (1951)	10/1/28	110.7	3 (4th)	1 (4th)	220	1666	1	1050	18/18	5 5/8	795	ACSR	2	3/8"	S	32	36	680	HILLS	ROCK CLAY SAND	—	25	NONE	—
			10/1/51	117.3	2 (3rd)	1 (3rd)	220	1631	1	1050	18/18	5 5/8	795	ACSR	2	3/8"	S	32	36	800	HILLS	ROCK CLAY SAND	—	25	NONE	—
21	"	BEAUHARNOIS-MASSON																				MOSTLY CLAY			RING & HORN	—
22	"	CHATS FALLS-LEASIDE	7/1/33	128.2	1	1	220	516	1	1310	18/18	5¾	795	ACSR	2	3/8"	S	32	36.5	850	FLAT	CLAY	—	25	NONE	—
23	"	BURLINGTON-BEAUHARNOIS-LEASIDE	8/1/41	44.8	2	2	220	273	2	870	18/18	5 1/4	500	CU	1	3/8"	S	25.3	34	550	ROLLING	CLAY	—	25	NONE	—
24	SO CAL EDISON CO LTD	NORTH & SOUTH LIGHTHIPE-LAFRESA	2/27/36	97	2	2	220	57	2	900	13/15	—	667	ACSR	1	2/0	CU	12	13	—	FLAT	SAND	—	5	RING & HORN	—
25	"	BIG CREEK-2-2A-3	7/5/28	59	1	1	220	29	1	1080	13/15	6¼	667	ACSR	2	3/0	CU	31	39	2950	MOUNTAINS	ROCK	LIGHT	5	RING & HORN	—
26 27	"	EAST & WEST EAGLE-BELL	1923	268	2	1	220	332 (28) 128	1	1090	13/15	6¼	667	ACSR	1&2	1/2"	S	19	23	1490	MOUNTAINS TO FLAT	ROCK CLAY SAND	LIGHT	5	RING & HORN	—
	"	BIG CREEK-MAGUNDEN	1/24/28	12.8	1	1	220	45.7	1	1480	13/15	6½	034	ACSR	2	3/8 5/8	S	33	34	2630	MOUNTAINS TO FLAT	ROCK CLAY SAND	LIGHT	5	RING & HORN	—
28	"	MAGUNDEN-EAGLE ROCK	11/4/26	102.6	1	1	220	478	1	1150	13/15	6¼	034	ACSR	2 (2)	3/8 5/8	S	30	31	3620	MOUNTAINS TO FLAT	ROCK CLAY SAND	SEVERE	5	RING & HORN	—
29	"	CHINO-BADGE	9/2003	26	2	1&2 (29)	220	116	1&2	1190	15/16	5 5/8	605	ACSR	1&2	1/2"	S	21	28	905	HILLS TO FLAT	CLAY SAND	—	5	HORNS	—
30	"	CHINO-LAGUNA BELL	12/28/28	33.4	1	1	220	132	1	1340	15/15	5¾ (9) 5 7/8	605	ACSR	1&2	1/2"	S	17	23	830	HILLS TO FLAT	CLAY SAND	—	5	RING & HORN	—
31	"	EAST & WEST LIGHTHIPE-LAGUNA BELL	10/1/27	7.0	2	1	220	68	1	1090	14/15	6½	034	ACSR	1	1/2"	S	14	16	80	FLAT	SAND	—	5	RING & HORN	—
32	"	BADGE-LIGHTHIPE	8/08/41	15.8	1	1	220	91	2	920	14/15	6½	605	ACSR	1	1/2"	S	12.5	13	68	FLAT	SAND	LIGHT	5	RING & HORN	—
33	"	EAST & WEST BIG CREEK	4/14/14	243.7	2	1	(32) 228	3448	1	700	11/13	5 5/8	667	ACSR	2	1/2"	S	8	11	2810	MOUNTAINS TO FLAT	ROCK CLAY SAND	LIGHT	5	RING & HORN	—
34	"	EAST & WEST LONG BEACH-LIGHTHIPE	6/6/28	9.8	2	2	220	55	2	345	15/15	6½	650	CU	1	4/0	CU	27	24	—	FLAT	SAND	—	5	—	—
35	"	NORTH & SOUTH BOULDER-CHINO	11/5/41	(33) 235.7	2	1	220	1652	1	750	15/16	5 5/8	605	ACSR	2	1/2"	S	18	31	2870	MOUNTAINS TO FLAT	ROCK CLAY SAND	LIGHT	15	HORNS	—

1. Suspension assemblies: 12 units after 1943–44.
2. First value suspension; second value dead end.
3. Armor rods on 25 per cent of line.
4. 37 inches after 1943–44.
4A. 4.8 after 1943–44.
5. 10.5 after 1943–44.
6. 637 towers: 1 circuit per tower. 134 towers: 2 circuits per tower.
7. 1 mile of ground wire at terminals only.
8. 20 per cent porcelain, 80 per cent glass.
8A. Apparently now being added.
9. Experimental devices on 25 per cent of line (not described).
10. 222.65 miles: 1 circuit per tower. 40.85 miles: 2 circuits per tower.
11. 60 miles in 1923, 9 miles added in 1925, 14 miles added in January 1944.
12. 142 miles: 2 circuits in 1933. 43 miles: 1 circuit added in March 1944. 29 miles: 2 circuits added in April 1944.
13. Data from 1935: 220-kv paper.
14. Except 43 miles of single circuit.
15. See note 23.
16. Estimated.
17. To August 1, 1945.

Table I. Lightning Performance and Design Feature of 220-Kv Lines (Continued)

TOWER FOOTING RES. (OHMS) BEFORE AUX. GROUNDING MAX	MIN	AVG	AFTER AUX. GROUNDING MAX	MIN	AVG	AUXILIARY GROUNDING	LIGHTNING PROT. WIRE SHIELD ANGLE AND LOW RES. AUX. GROUNDING	TOP COND. ABOVE GROUND (FT.)	WIRE SPACING AT TOWER (FEET-MIN) COND. HORIZ.	COND. VERT.	GR WIRE HORIZ.	GR WIRE VERT.	LIGHTNING OUTAGES ONE CIRCUIT / TWO CIRCUIT 1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	AVG. PER YEAR	AVG. PER (100 MI. PER YEAR 50 (24) ACTUAL	LEVEL	LINE CLEARANCE TO STRUCTURE AT COND. SWING OF: (DEG.) FT.	MIN. NO. INSUL. IN STRING EQUIV. 5¾ IN. UNITS	1½ X 40 μSEC CRITICAL POS. IMPULSE KV. MAX.	MIN.	MIN. CLEAR. ANG. AT 30° SWING	MAX. SHIELDING ANGLE (DEGREES) (25)	REF
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	61
—	—	—	—	—	—	NO	NO	NO	44.2	23.5	—	25.0	14.8	3	1	10	9	10	4	5	4	6	8	11	—	6.8	5.4	4.3	72	45	15	1345	1340	37/40	1
—	—	150	—	—	LOW	2 CONT CP	NO	NO	73.5	23.5 33.5	12	33.5	38.8	3/11	1/3	2/3	3/5	1/7	4/0	2/3	0/2	0/2	0/2	1/0	—	19/35	14/0	6.4	(68) 73	30	8.43	820	780	27	2
700	10	150	45	—	—	CP & GR	NO	YES 2 CP	63.3	25.3	—	26.5	12.8	—	—	—	—	5	2	0	2	1	1	1	—	1.7	1.6	5.3	65	30	14.48	1310	1220	43/46	3
800	5	50	—	—	—	2 CONT CP+CP	NO	NO	62.2	26.5	—	37.0	22.5	—	—	—	—	—	—	0	0	0	0	0	—	0	0	0	55	30	12.30	11.30	10.40	39/39	4
—	—	—	—	—	24.2	MISC CP	NO	NO	62.0	25.5	—	25.5	16.1	0	1	2	3	1	0	2	4	1	1	0	—	1.4	2.4	3.4	60	30	16	1425	1425	38	5
—	—	—	—	—	—	ONE GOD CP	NO	NO	62.0	25.5	—	25.5	16.1	0	0	2	2	1	1	0	2	0	0	0					80	30	18	1429	1475	38	6
61	47	15	—	—	—	NO	NO	NO	65.9	26.3	—	23.8	13.6	0	0	2	2	1	1	0	0	0	0	0	2.0(1)	} 0.83	1.7	2.4	78	30	16	1425	1445	47½	6A
330	5	75	40	1	5	CP	NO	NO	66.0	22.5	—	23.1	10.1	12	14	28	29	18	18	16	(12.8)	0	1	2	3(1.0)				70	30	14	1265	1300	47	7
300	1	64	27	1	18	CP	NO	NO	62.5	28.5	—	28.5	14.8	0	1	1	1	0	0	(18)	(16)	(28)	(18)	(8)	—	12.9	11.5	17.0	76	30	14	1425	1405	44	7A
165	0	6	—	—	—	NO ONE	NO	NO	62.5	28.5	—	28.5	14.8	0	1	0	0	1	1	(18)	(18)	(18)	(18)	(18)	—	} 0.13	0.96	1.45	76	30	16.65	1480	1405	44	8
28	1.8	10	—	—	—	650 CP	NO	NO	62.7	25.5	—	43.0	16.2	0	1	1.0	0	1	1	1	2	0	0	2	—				73	30	16	1425	1360	49/53	8A
450	1	67	19	1	10	CP	NO	NO	58.3	28.3	—	42.3	25.7	—	—	—	—	0	0	0	1	1	1	0	—	0.43	0.86	1.20	90	30	18.35	1615	1655	15/39	9
430	1	74	32	1	12	CP & GR	NO	NO	58.3	28.3	—	42.3	25.7	0	0	0	0	0	0	0	0	0	1	0	—	0.091	0.099	0.137	90	30	18.35	1615	16.35	15/39	10
—	—	—	5	—	1.8	CP & GR	NO	NO	66.0 (58) 65.2	46.0 (40) 33.3	20.6	46.0 (40.0) 46.3	22.5 (19.6) 19	—	—	—	—	—	—	0	0	0	0	0	—	0	0	0	95	30	18	1585	1710	18/33	11
—	—	—	850	1.3	—	GR	(9)	(9)	37	2.7	—	37	23 (1)	—	—	—	—	—	—	—	—	—	5	1	8	4.7	2.6	16.2	50	30	16	1425	945	—	12
—	—	—	350	1.2	—	GR	(9)	(9)	37.6	38/31	20.3	—	22.4 (1)	—	—	—	—	—	—	—	—	—	7/1	6/2	3/1	(28) 5.1/0.3	64/1.6	40/1.0	50	30	16	1425	945	—	13
150	—	1	76	0.4	0.8	2-CP	NO	NO	77.1	32.5	—	50	32	—	—	—	—	1/0	0/0	0/0	1/0	0/0	0/0	1/0	0/0	—	0.026	0.08/0	0.1/0	90	30	21	1825	1695	13/36	14
150	—	1	76	0.4	0.8	2-CP	NO	NO	77.1	32.5	—	50	32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	90	30	21	1825	1695	13/36	15
—	—	—	(no) 500	(no) 2	(no) 3	2" SG PLATE 2" SG PLATE	NO	YES GR YES GR	44.1	19.5	—	—	—	2	1	3	2	1	2	2	0	2	0	2	— (28)	1.5	1.9	19.0	95	30	10.57	1000	869	—	16
—	—	—	11 (16)	(no) 0.90	4 (16)		NO	GR	84.9	24	15	—	—	4/0	8/0	1/0	0/0	4/0	(10/0)	1/0	1/0	5/0	1/0	1/0	(0.0)	38/0	25/0	25/0	5	30	11.05	1030	949	—	16A
—	—	—	(no) 100 (16) 100	(16) 2. (16) 2	(no) 15 (16) 15	GR	NO	NO	46.7	28	—	—	—	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	d/0	0/0	0/0	— (28)	0/0.09	0/0.56	0/5.6	45	30	12.46	1145	865	—	17
—	—	—	180	2	15	GR	NO	NO	85.3	28	15	—	—	0/0	2/0	3/0	4/0	0/0	7/0	0/0	4/1	1/0	1/0	0/2	2/0	13/0.25	2.0/0.21	20/2.1	43	30	12.46	1145	825	—	17A
(no) 100	(no) 2	(no) 15	—	—	—	NO	NO	NO	—	27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3 (28)	1.5	4.3	45	55	30	14	1245	1040	—	18
(no) 100	(no) 2	(no) 15	—	—	—	NO	NO	NO	87	27.3	16	—	—	0/0	0/0	0/0	0/0	1/0	1/0	3/0	2/0	1/0	1/0	1/1	2/0 (28)	5.0/0.8	0.7/0.08	7.1/0.8	51	30	14	1245	1080	—	18A
(no) 100	(16) 2	(16) 15	—	—	—	NO	NO	NO	87	27.3	16	—	—																51	30	14	1245	1080	—	18B
81	1	11.5	—	—	—	NO	NO	NO	70.5	22.3	—	31.9	16.5	—	—	—	—	—	—	37	22	26	33	12.8	0	—	19.8	8.4	2.8	51	30	13	1105	940	21/44	19
300	3	29	—	—	—	NO	NO	NO	54.7	25.3	—	24.8	13.3	1	2	1	4	3	0	0	2	2	2	2	—	1.7	1.55	2.10	8	30	15 18	1415	1475	41/45	20
1550	2	250	1550	2	250	CP (2.0)	NO	NO	54.7	25.3	—	24.8	13.3	10	4	6	4	9	12	4	17	6	18	16	—	9.64	8.24	16.48	8	30	15 18	1415	1475	41/45	20A
300	2	25	—	—	—	NO	NO	NO	54.7	25.3	—	24.8	13.3	1	2	1	0	0	2	0	1	0	1	1	—	0.82	0.64	1.28	18	30	15 78	1415	1475	41/45	21
14	1	3.7	—	—	—	NO	NO	NO	—	34/ 34	20	—	—	—	—	—	—	—	—	—	—	1	3	0	—	1.3	2.97	5.94	8	30	15 78	1415	1475	—	22
600	1	47	25	1	6.5	CP	NO	NO	54.7	25.3	—	21.3	24.9	—	—	—	—	—	—	—	—	3	0	4	1	—	2.0	0.67	1.34	8	30	15 78	1415	1475	29/32	23
—	—	—	—	—	—	NO	NO	NO	121.1	31.0	20.0	—	17.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	41	24
—	—	—	—	—	—	NO	NO	NO	51.9	22.2	—	24.0	12.7	0	0	0	0	0	0	0	0	0	0	0	—	0	0	0	—	—	14.05	12.70	—	39/44	25
—	—	—	—	—	—	NO	NO	NO	52.5	22.2	—	24.0	12.5	0	0	0	1	0	0	0	2	0	1	1	—	0.46	1.72	1.72	—	—	13	1105	—	39/44	26
—	—	—	—	—	—	NO	NO	NO	55.3	22.2	—	24.0	12.7	0	0	0	0	0	2	0	1	0	0	2	—	0.43	0.35	3.5	6	30	14.05	12.70	11.25	39/44	27
—	—	—	—	—	—	NO	NO	NO	53.3	22.2	—	24.0	12.7	1	3	1	0	12	7	3	4	1	4	3	—	(18) 3.54	3.45	34.5	6	30	14.05	12.70	11.25	39/44	28
—	—	—	—	—	—	NO	NO	NO	22.7 / 45.8 (34)	16.5 (34)	28.7 / 23	— (34)	24	11.7	—	—	—	—	—	0	0	0	0	0	0	—	0	0	0	45	30	13	1345	865	41/46	29
—	—	—	—	—	—	NO	NO	NO	70.6	23.0	—	24.0	11.7	—	—	—	—	—	—	—	—	0	0	0	—	0	0	0	45	30	15	1345	865	43/48	30
—	—	—	—	—	—	NO	NO	NO	51.4	22.2	—	13.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15.15	1360	—	39/0	31
—	—	—	—	—	—	NO	NO	NO	122.7	33.0	20	—	16	—	—	—	—	—	—	0	0	0	0	—	0	0	0	—	—	15.68	14.05	—	46	32
—	—	—	—	—	—	NO	NO	NO	35.7	17.2	—	18	10.8	1/0	0/0	0/0	1/0	2/0	4/0	2/0	1/0	0/0	1/0	2/0	—	1.2/1.0	0.96/0.5	2.0/0.4	—	—	11	1025	—	37/44	33
—	—	—	—	—	—	NO	NO	NO	110	33	20	—	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18.85	1510	—	44	34
300	0.5	—	70	0.3	1.8	Tower CP	NO	NO	70.6	23	—	24	11.7	—	—	—	—	—	6	3	0	1/0	1/0	0/0	—	0.83/0	0.36/0	1.2/0	45	30	13	1345	865	41/46	35

18. Data not reported.

18A. First value for 2-circuit towers. Second value for 1-circuit towers.

19. To September 1, 1945.

20. Ground wire installed 1943.

21. Line completely equipped with ground wire 1941.

22. Counterpoise as required to reduce resistance to 25 ohms. First 10 miles from Chats Falls only

23. Operating at 165 kv to January 1944.

24. 88.5 miles is 3 circuit. 28.8 miles is 2 circuit.

25. First number for outer conductor. Second number for middle conductor.

26. On basis of 50 isokeraunic level.

27. First figure for east line. Second figure for west line.

28. No ground wire for 64 miles of line due to severe sleet loading.

29. 17 miles: 1-circuit towers. 9 miles: 2-circuit towers.

30. 17 miles: 2-ground wires. 9 miles: 1-ground wire.

31. Also some 12 and 14 units of fog type in suspension.

32. Originally designed for 150 kv.

33. North line June 22, 1939.

Table II. Extent of 220-Kv[1] Lines

13 Companies, 35 Lines

		Approximate Miles
Single circuit	Right of way	1,838
Two circuit on single towers	Right of way	717
Two circuit on separate towers	Right of way	970
Three circuit on separate towers	Right of way	463
Total miles	Right of way	3,988[2]
Total circuit miles of 3-phase line		6,601[2]

1. 135.3 miles of right of way operated at 190 kv and 263.5 miles operated at 287 kv.

2. Not including 550 miles of right of way for company references 12 and 13 (Table I) which were mentioned but not reported on.

Table III. Average Lightning Outages[1] on 220-Kv Lines

	Right of Way, Miles	Outages Per Year Actual	Outages Per 100 Miles of Line Per Year on Basis of 50 Storms Per Year
All lines	3,988.5	92.83	9.97
Lines without ground wires	916.8	21.92	19.30
Lines with ground wires	3,071.7	70.91	7.19
With ground wires[3]	349.0	32.70	24.20
With 1 ground wire	87.1	1.3	4.3
With 2 ground wires	2,446.8	32.91	3.8
With 1 and 2 ground wires[3]	86.2	0.46	0.53
With ground wire on part of line only	102.6	3.54	34.5

1. Based on actual outages and actual miles (not average of columns 55 and 56, Table I).

2. Lines having ground wire added during period of outage record 1934–45.

3. Lines having 1 ground wire on part of line, balance 2 ground wires.

higher than 2-line outages, as would be expected. The one exception is the case of line reference 2, where the single-circuit outages on a 100-mile-per-year basis is 1.4, and double-circuit outages 2.6, or nearly double.

The outage record seems to indicate clearly that, even with the highest insulation used in 220-kv lines, the insulation alone does not render the line lightning-proof without the aid of other remedial measures, such as ground wires and low tower-footing resistances.

Overhead Ground Wires

Benefit of Use. A summary of lightning outages for all lines and for lines with and without ground wires is given in Table III. Of the nearly 4,000 miles of line (right of way) covered by this report, the outages on a 100-miles-of-line-per-year basis at a 50 isokeraunic level is 9.97. Twenty-three per cent of the line mileage does not have ground wire, and its outage record is 19.3 per 100 miles of line per year. Of the line mileage 63.5 per cent has either one or two ground wires over the entire line, and its outage record is 3.8 to 4.3 outages on the above basis, the lower figure being for two-ground-wire lines, and the higher for the single-ground-wire groups.

In Figure 4 a further breakdown of the outage data on nonground-wire and ground wire lines where tower footing resistances were reported is shown. Based on a 50 isokeraunic level, the average outages per 100 miles of line per year is 27.5 for lines without ground wires, and 4.5 for ground wire lines. Ground wire lines of over 25 ohms average footing resistance have 15.4 outages, and lines with 25 ohms or less 1.94 outages.

The foregoing record clearly demonstrates the value of overhead ground wires and low footing resistance in reducing lightning outages.

Height and Spacing. Column 40 gives the horizontal spacing between the overhead ground wires where there are two ground wires. These spacings vary from 21 to 48 feet for the lines in the 190- to 240-kv class and from 40 to 50 feet for the 287-kv lines. The height of the ground wire plane above the plane of the conductors at the towers is given in column 41. This varies from approximately 10 to 29 feet for the 190- to 240-kv class lines and is 32 feet for the 287-kv lines. In Figure 5 is plotted the height of ground wires above conductors from column 40 against outages per 100 miles per year at isokeraunic level 50 from column 56. In cases where two ground-wire heights are given in the length of the line, the average height is plotted.

There does not appear to be any consistent relation between height of ground wires and outages experienced. A number of lines with heights ranging from 22.5 to 32 feet show outages from zero to 1.34 per 100 miles per year (column 56), but other lines with heights from 11.7 to 16.2 feet show outages in the same range. For example, two lines, 21 and 23, with the same impulse insulation level, 1,415 kv, show practically the same outage performance (1.28 and 1.34 per 100 miles per year,, although one has the ground wires 13.3 feet and the other 26.9 feet above the conductors.

Shielding Angle. In column 62 is given the angle between a vertical line through the ground wire and the slanting line between the ground wire and line conductor, or the so-called shielding angle. This angle varies widely, from a minimum of 13 degrees to a maximum of 47 degrees for the outside conductors of horizontally arranged lines and for the top conductor of vertically arranged lines. For the middle conductors of horizontal lines the angle is in one case as much as 53 degrees. In Figure 6 are plotted shielding angles from column 62 against tripouts per 100 miles per year at isokeraunic level 50 from column 56. Where the angle for middle conductor is different from the angle for outside conductor, the angle for the outside conductor is used.

The relationship between shielding angle and outages does not follow a consistent pattern. There is a zone of low outages with shielding angles ranging from 13 to 44 degrees (zero to 1.5 outages per 100 miles per year). Low footing resistance seems to be more important than small shielding angle.

Insulation Values

The flashover strength of the line is the lower of the values given in columns 60 or 61, that is, the insulator string flashover or the flashover from conductor to tower when the conductor is in the swung position.

In Figure 4 are plotted the impulse flashover strengths of the various lines (taking the value from column 60 or 61, whichever is lower), against the number of outages reduced to a common isokeraunic level of 50. The points are pretty well scattered, as a result of the masking effect of ground wires and tower footing resistance already discussed.

It will be noted, on comparing columns 60 and 61, that in many cases the flashover strength in column 61 is less than the insulator flashover in column 60. That is, the clearance from conductor to tower is not sufficient to develop the full strength of the insulator strings.

Mid-Span Flashovers

The possibility of getting mid-span flashovers long has been an unanswered question. If such occur to any extent, they are always difficult to detect, as the evidence, such as burned conductor at mid-span, is almost impossible to locate with certainty in the field.

A study of this feature from the data of Table I shows that mid-span clearances between ground wires and conductors have been increased by all companies. The vertical separation between ground wire and top conductor varies from 9.8

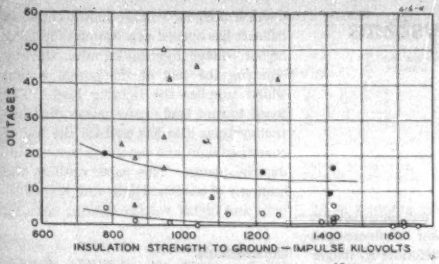

Figure 4. Insulation strength to ground versus outages per 100 miles of line per year at isokeraunic level of 50

△—No overhead ground wire
•—Over - 25 - ohms footing resistance
○—25-ohms footing resistance

to 32 feet at the tower (column 41) with an increase of minus 3 feet to 18 feet at mid-span (columns 19 and 20) with a general range of 10 to 15 feet increase on the lines of newer design where this feature apparently was given consideration. Whether this increase in ground-wire-to-conductor spacing was predicated on lightning performance only or, in some cases, on sleet considerations, the records at hand do not show.

Taking the rough average height of ground wire above conductor at the tower as 15 feet, the increase in mid-span as 15 feet, and an average shielding angle of 30 degrees, there results an average ground-wire-to-line-wire separation of about 35 feet. At 180 kv per foot sparkover in air, this spacing would have a 1.5x40-microsecond positive wave critical flashover of about 6,300 kv and, of course, much higher on a steep-front short-tail lightning voltage wave. Comparing these values with the insulation flashover at the tower, which range from about 800 to 1,600 kv, there does not seem much likelihood of mid-span flashover in general, even with waves of extremely rapid rate of rise.

Tower Footing Resistance

The data given on tower-footing resistance are rather meager in many instances (columns 28 to 33 inclusive) but do indicate extremely wide variations between maximum and minimum on particular lines, for example, 2 to 1,550 ohms on line 20*A*.

In some cases a marked decrease may be noted after counterpoises or ground rods have been used. As an example, the maximum footing resistance of line 3 came down from 700 to 45 ohms.

Means for Reducing Footing Resistances. In about 68 per cent of the lines reported, means have been taken to reduce the tower footing resistances. These means consist of various arrangements of counterpoises, driven rods, and buried plates, the percentages of the cases where

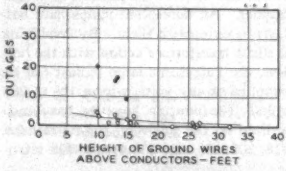

Figure 5. Height of overhead ground wires versus outages per 100 miles of line per year at isokeraunic level of 50

•—Over 25-ohms footing resistance
○—25-ohms-or less footing resistance

improvements have been made being about 62, 28, and 10 per cent respectively.

Effect on Outages. In Figures 4, 5, and 6 are plotted line outages against insulation strength, height of ground wire, and shielding angle, for two different ranges of footing resistance, that is, over 25 ohms and 25 ohms or less. In some instances a change was made in the shielding or in the footing resistance during the period covered, and these data were prorated for the figures. The benefit of low footing resistance is apparent from these figures.

Line Damage

Although a definite attempt was made by specific questions in the questionnaire to obtain information on line damage including damage to insulators, broken strings, and damaged conductors, replies

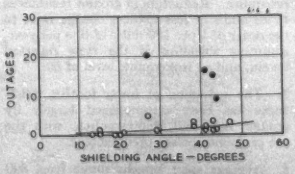

Figure 6. Shielding angle of ground wire versus outages per 100 miles of line per year at isokeraunic level of 50

○—25-ohms-or-less footing resistance

indicated that these are so extremely rare as not to present a real problem. Only two companies reported damage of any kind to hardware or conductors. One reported two cases where an insulator string was severed, and the other reported shattered insulators.

Likewise, duration of line tripouts of lines in this voltage class does not appear, from the replies received, to be of great concern. In one of the cases mentioned the line was out for ten hours. The second company reported merely "long outages" without giving the time involved.

Improved Lightning Performance Being Considered

Only three companies report that they are giving any consideration to making further changes in their line construction to improve its lightning performance. One (reference 3) is adding two counterpoises. The second company (references 12 and 13) is experimenting with devices not described in an attempt to better the line performance. Still a third company (references 16 and 16*A*) reports that it is considering installing ground wires because of the increase in lightning outages reported during the past year. This improvement apparently is being considered on only one line of the company. It should be noted in this connection that this line is in an area where the isokeraunic level is indicated as 5.

Summary and Conclusions

The lightning outage records of 35 transmission lines in the 220-kv class (operating at 190 to 287 kv) have been presented and discussed. Data also are given on some of the design features of these lines which are believed to be factors in their lightning performance.

If equal lightning intensities are assumed, theory and experience have shown that certain factors have a predominating influence on flashovers and outages, namely:

1. Overhead ground wires.
2. Insulation strength.
3. Tower footing resistance.

In the data disclosed by the present survey, it is difficult to separate definitely these influences and to place relative values upon them. However, the following conclusions seem to be justified:

1. The beneficial effects of overhead ground wires clearly is indicated in reducing lightning outages. Nonground-wire lines have a yearly outage record per 100 miles of line per year of 19.3 against 7.19 for lines now

Combined Light and Power Systems for Industrial Plants

D. L. BEEMAN
MEMBER AIEE

THE upward trend in illumination levels in industrial plants has resulted in an increased power demand of the lighting load. Illumination levels of 50 foot-candles are in general considered good practice at the present time, with some thinking of illumination levels as high as 100 foot-candles. The lighting load is a sizable portion of the total plant load. In many average manufacturing plants the lighting load will represent 2 to 4 volt-amperes per square foot, and the power load 8 to 10 volt-amperes per square foot. The same technique that has been applied in distributing power to machine tools and other power loads will pay dividends in distributing power to the lighting load.

For incandescent lamps 120-volt systems have been used almost universally. Higher-voltage incandescent lamps are fragile and generally not satisfactory.

With the introduction of fluorescent lamps the 120-volt restriction no longer applies. All fluorescent lamps have ballasts in series with them. By combining a slight transformer action with the ballast, the fluorescent lamp ballast can be supplied at any voltage from 120 to 260 volts. The industry, however, has standardized on the following ballast ratings: 118, 208, 230, and 260 volts. The introduction of higher-voltage fluorescent lamp ballasts has opened new avenues for using higher-voltage lighting circuits, thereby reducing the cost of the power system which supplies the lighting load. The trend toward load center power distribution systems also has enabled the use of combined light and power systems for industrial plants. This paper outlines the economy of combined light and power systems and higher-voltage lighting circuits.

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Conclusions

1. Combined light and power systems are less expensive than systems using separate substations for light and power.

2. High-voltage lighting circuits are generally most economical when using 260-volt 2-lamp 100-watt fluorescent lamp ballasts, so that the lighting load may be operated directly off the 480-277-volt substation

Table I. Cost Per Kilovolt-Ampere of Transformers, Panel Boards, and Wiring as a Function of Ballast Voltage

Line	Ballast Voltage	Transformer Rating	*Transformer Cost, Installed	**Panel Board Cost, Installed	Branch Wiring Cost (See Figure 8)	Total Cost
1	118	3 phase, 480–208Y–120 volt	12.50	5.60	6.40	$24.50
2	208	3 phase, 480–208Y–120 volt	12.50	5.60	3.80	21.90
3	120	1 phase, 480–240–120 volt	11.50	5.60	6.40	23.50
4	230	1 phase, 480–240–120 volt	11.50	5.25	3.00	19.75
5	260	1 phase, 480–265–132.5 volt	11.50	4.85	2.50	18.85

* Installation included at $2.50 per kilovolt-ampere.

** Installation included at $1.85 per kilovolt-ampere.

having ground wires (Table III). For lines having ground wires throughout the ten years covered by this report, the corresponding outage figures are 4.3 for one-ground-wire lines and 3.8 for two-ground-wire lines. One outstanding case of the benefits of ground wires is shown on line reference 7, where the observed outages averaged 19.2 for 7 years before the line had ground wires and 1 per year for 4 years after 2 ground wires were installed.

2. The sag of ground wires ranges from 11 to 45 feet, averaging 25 to 30 feet. Vertical separations between ground wire and line wire at mid-span are greater than at the tower by a range from minus 3 to 18 feet, with a general average of about 15 feet.

3. The shielding angles of ground wires vary from 13 to 59 degrees with a trend indicated that the smaller shielding angles reduce line outages.

4. Regarding overhead ground-wire location, in general these are placed from 9.8 to 32 feet above the horizontal plane of the top conductors at the towers. The general average of elevation of the ground wire, however, is about 15 feet above the top conductor.

5. Insulation supplied by a practical length of insulator string, or by a similar air clearance from conductor to tower, is not sufficient in the 220-kv class to prevent lightning flashover of the line. Flashovers have been experienced on the lines reported with impulse strengths as high as 1,600 kv.

6. Where reduction of tower footing resistances has been made, the final average values range in the general order of 1 to 20 ohms. The data submitted show definite benefits derived from the lowering of ground resistance. Reduction of ground resistances to 10 ohms or less reduces outage rates to the order of 1 per 100 miles of line per year, assuming shielding of the type reported herein, and an isokeraunic level of 50.

7. The reduction of tower footing resistances has been accomplished largely by ground rods and counterpoises, with the use of counterpoises predominant.

8. Average span lengths range from 500 to 1,480 feet with the majority of lines having a span of approximately 1,100 feet. There are insufficient data to indicate the effect of these practical span lengths on the lightning outage record of the lines.

9. Arcing devices on insulator strings, which were prevalent in the earlier designed lines, are being omitted on later built lines, with no adverse operating experience reported.

10. Damage to lines, caused by lightning, appears in general to be very infrequent and of minor concern to the service performance of the lines. Only two companies report prolonged outages; these involved shattered or broken insulators. Both cases were on lines not equipped with ground wires.

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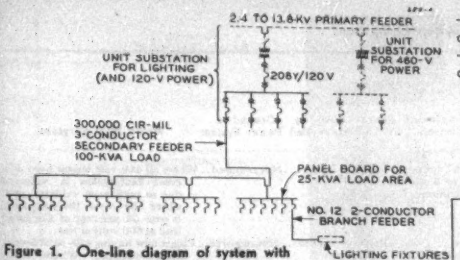

2.4 TO 13.8-Kv PRIMARY FEEDER
UNIT SUBSTATION FOR LIGHTING (AND 120-V POWER)
UNIT SUBSTATION FOR 460-V POWER
208Y/120 V
300,000 CIR-MIL 3-CONDUCTOR SECONDARY FEEDER 100-KVA LOAD
PANEL BOARD FOR 25-KVA LOAD AREA
NO. 12 2-CONDUCTOR BRANCH FEEDER
LIGHTING FIXTURES

Figure 1. One-line diagram of system with separate substations for power and light services—system A

without intervening transformation. Generally 120 volts are most economical overall for 40-watt fluorescent lamp installations.

3. With the modern load center power system, the objectionable flicker from welders practically can be eliminated by using separate transformers for resistance welders or by serving the lights from one transformer and the resistance welders from another in a secondary selective system, Figure 17.

Combinations Studied

Three basic combinations of power supply for lighting systems are considered in this paper. These are:

1. A 208Y–120-volt 3-phase 4-wire power system for lighting load, with separate substations for 460-volt power for motors, and the like, Figure 1.

2. Combined substations for power and light, that is, one 480-volt substation serving motors directly and the lighting load through step-down dry-type transformers located at strategic points through the factory, Figure 2.

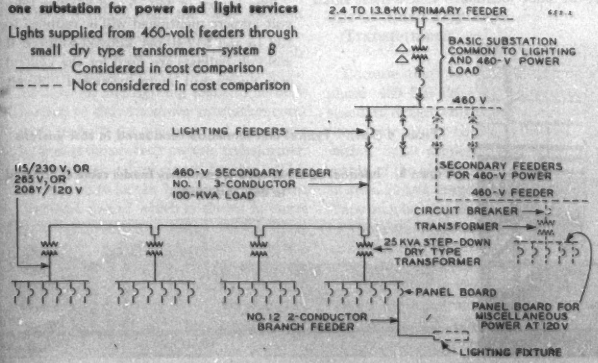
3. A 460Y–265-volt combined power and lighting system in which the motors are operated at 3 phase, 460 volts and fluorescent lights from phase to neutral at 265 volts, from the same substation, Figure 3.

Figure 2. One-line diagram of system with one substation for power and light services

Lights supplied from 460-volt feeders through small dry type transformers—system B

——— Considered in cost comparison

- - - - Not considered in cost comparison


2.4 TO 13.8-KV PRIMARY FEEDER
BASIC SUBSTATION COMMON TO LIGHTING AND 460-V POWER LOAD
460 V
LIGHTING FEEDERS
115/230 V, OR 265 V, OR 208Y/120 V
460-V SECONDARY FEEDER NO. 1 3-CONDUCTOR 100-KVA LOAD
SECONDARY FEEDERS FOR 460-V POWER
460-V FEEDER
CIRCUIT BREAKER
TRANSFORMER
25 KVA STEP-DOWN DRY TYPE TRANSFORMER
PANEL BOARD
NO. 12 2-CONDUCTOR BRANCH FEEDER
PANEL BOARD FOR MISCELLANEOUS POWER AT 120 V
LIGHTING FIXTURE

——— Considered in cost comparison

- - - - Not considered in cost comparison

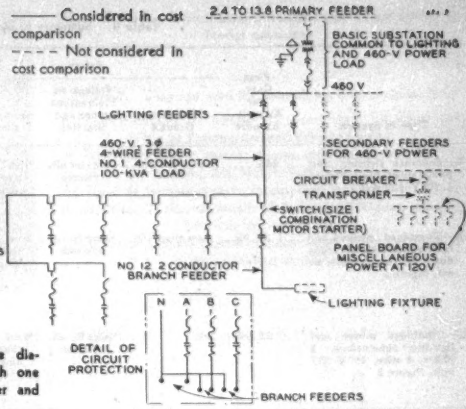

2.4 TO 13.8 PRIMARY FEEDER
BASIC SUBSTATION COMMON TO LIGHTING AND 460-V POWER LOAD
460 V
LIGHTING FEEDERS
460-V, 3Φ 4-WIRE FEEDER NO. 1 4-CONDUCTOR 100-KVA LOAD
SECONDARY FEEDERS FOR 460-V POWER
CIRCUIT BREAKER
TRANSFORMER
SWITCH (SIZE 1 COMBINATION MOTOR STARTER)
PANEL BOARD FOR MISCELLANEOUS POWER AT 120 V
NO. 12 2 CONDUCTOR BRANCH FEEDER
LIGHTING FIXTURE
N A B C
DETAIL OF CIRCUIT PROTECTION
BRANCH FEEDERS

Figure 3. One-line diagram of system with one substation for power and light services

260-volt fluorescent lights supplied from 460-volt feeders—system C

Items Included in Study

It is assumed that the primary feeder system is the same, regardless of which of the three afore-mentioned systems are selected. Therefore, the items considered are the step-down substations, secondary feeder circuit breakers, secondary feeders, dry-type transformers, panel boards, and branch wiring, as illustrated by the solid lines in Figures 1, 2, and 3.

The type of unit substation considered throughout this study is shown in Figure 4. To allow for diversity it is assumed that 1 kva of transformer capacity in the substation would have 1.25 kva of lighting load connected to it. Hence, the secondary feeder circuit breakers and cable have a capacity of 1.25 times the transformer kilovolt-ampere rating of the unit substation.

Installation cost of the substations is considered at 20 per cent of the substation price. These values—that is, 20 per cent for installation and 1.25 allowance for diversity—will be used throughout this study. The cost of substations as a function of kilovolt-ampere capacity is shown in Figure 6.

All secondary feeders are assumed to be varnished-cambric-insulated interlocked-armor cable, Figure 5.

The branch wiring from the panel board or control switch to the trough of the fluorescent lighting fixtures is included, but the wiring within the fixtures is not. The branch circuits have been limited to number 12 BX wire, with a current carrying capacity of 20 amperes, because it is believed that a 20-ampere fuse or circuit breaker is the largest which will give reasonable short-circuit protection to the ballasts. In most cases the load current per circuit is about 16 or 17 amperes. Branch circuit wiring costs are assumed to be 25 cents per foot of 2-conductor number 12 BX. To approximate the amount of branch circuit wiring for the various voltages, typical layouts were made—Figure 8.

System A—Separate Substations for Light and Power, Figure 1

This type of system may operate at either 208Y–120 volts, 3 phase, 4 wire, or 230–115 volts, single phase, 3 wire. In line with modern practice the 208Y–120-volt system will be used in the comparison.

A 208Y–120-volt system will care for the general area fluorescent lights, as well

Table II. Summary of System Comparisons

Type of System	First Cost, Per Kilovolt-Ampere	Safety: Voltage to Ground	Safety: Voltage on Fluorescent Lamps and Starters	Short-Circuit Current	Flicker Caused by 460-Volt Power Load	Ground on Power System	Where Most Adaptable
A—Separate lighting and power substations, Figure 1, 208Y–120 volt	$45	Less than 150	Same for all systems	High (more than 5,000 amperes)	None	Not required	Where all 460-volt busses have too great fluctuations in voltage, due to resistance welders; and where the total 120-volt load is over 50 per cent of the total load at 600 volts or less
B—Combined power and lighting substations, step-down lighting transformers, Figure 2	39.95	Less than 150	Same for all systems	Low (less than 5,000 amperes)	Possible (due to resistance welders)	Not required	Plants now having 460- or 575-volt delta systems. Where total lighting and miscellaneous load is less than about 50 per cent of the total load at 600 volts or less. Adaptable for incandescent, fluorescent, or any other kind of lighting
C—Combined power and lighting substations, 3 phase, 4 wire, 480Y–277 volt, Figure 3	23.95	265	Same for all systems	*Low (less than 3,000 amperes)	Possible (due to resistance welders)	Yes	In new factories, or in old factories where new 460-volt power systems are installed. Adaptable only for fluorescent or mercury-vapor lighting. Not adaptable to 575-volt power systems

* Using size 1 fused combination motor starters for controlling lighting circuits.

as the miscellaneous 120-volt power and lights. The system is laid out on the basis of $4^1/_4$ volt-amperes load per square foot to evaluate that part of the substation and secondary feeder cost which must be charged to the general area lighting system.

The minimum installed cost of the 208Y–120-volt substation and secondary feeders is $28.75 per kilovolt-ampere of substation rating when using 500-kva substations, the most economical size—top curve, Figure 6. A deviation from this size will increase the cost per kilovolt-ampere as shown by the curves.

The load per secondary feeder has been assumed to be 100 kva. The 4-conductor 300,000-circular-mil secondary-feeder cable has an installed cost of $2 per foot. Each feeder will supply four circuit breaker panel boards of the type shown in Figure 7, with 25 kva of lighting load per panel board. The total cost of panel boards is estimated at $5.60 per kilovolt-ampere installed and wired (installation $1.85 per kilovolt-ampere).

It is realized that the circuit breakers in these panel boards do not have sufficient interrupting rating (only 5,000 amperes) for this service. However, there are no available devices which meet the space requirements for this service and which have adequate interrupting rating for the short-circuit current duty imposed on them.

The total cost of system *A* is

$28.75 . . . Substations and secondary feeders
5.60 . . . Panel boards
6.40 . . . Branch wiring at 120 volts

$40.75

per kilovolt-ampere of lighting demand.

In general lighting substations as large as 500 kva (the most economical size from Figure 6) are not used. The substations often are laid out with a larger power and a smaller lighting substation at the same location. Where these small lighting units, that is, 150 kva, are used, the cost of the substation is increased. Using the cost from the top curve on Figure 6 for 150-kva substations, the total cost of system *A* is increased to

$33.00 . . . Substation and secondary feeders
5.60 . . . Panel boards
6.40 . . . Branch wiring at 120 volts

$45.00

per kilovolt-ampere of lighting demand.

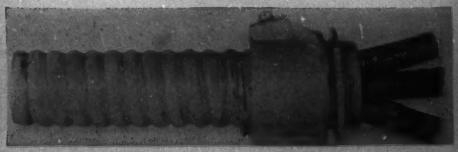
The cost may be increased even further if a primary protective device is required on the small lighting substation transformer. Hence, the cost of system *A* may go as high as $75 per kilovolt-ampere of lighting demand. Therefore, it is believed that $45 per kilovolt-ampere is a fair average to use in the general comparison with other systems.

System A With 208-Volt Ballast

The figures of $40.75 and $45 per kilovolt-ampere mentioned will be reduced to $38.15 and $42.40 per kilovolt-ampere, if 208-volt ballasts are used for the general area fluorescent lamps instead of 118-volt

Figure 4 (left). Typical unit substation considered in cost analysis

Figure 5. Interlocked-armor type of secondary feeder cable considered in cost comparison



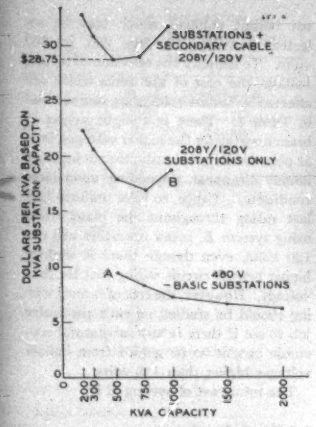


Figure 6. Cost of unit substations and secondary feeders as a function of unit substation size

20 per cent for installation
Feeder capacity is 125 per cent of substation capacity

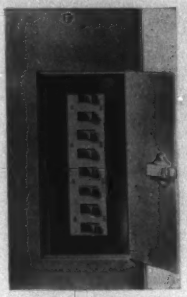


Figure 7 (left). Typical circuit breaker panel board for branch feeder protection

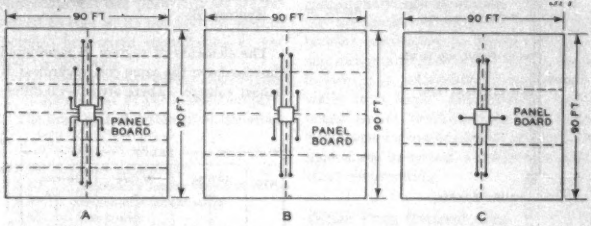
Figure 8. Diagrams used for determining branch circuit length

All branch circuits are number 12 2-conductor BX wire. 25-kva of lighting demand per load area

A—120-volt 1-phase branch circuits; total length 510 feet, including 240 feet for vertical runs

B—208-volt 1-phase branch circuits; total length 1/3 of 510 feet to adjust for 7 circuits; length of 7 circuits 300 feet, including 140 feet for vertical runs

C—230-volt 1-phase branch circuits; total length 240 feet, including 120 feet vertical runs



ballasts considered in the foregoing tabulations. The saving is made in branch circuit wiring only because the system is 3 phase, 208Y–120 volt up to that point. Since detail circuit arrangements may alter materially the branch circuit wiring costs, it is felt that the saving from using 208-volt ballasts rather than 118-volt ballasts may not be as great as shown. For the sake of uniformity of ballasts throughout a plant, many operators would use 118-volt rating for all ballasts if they elected to use system *A*.

System B—Combined Light and Power Substation, Figure 2

It is assumed that the same 480-volt substation will supply power to the 460-volt power feeders and to the 460-volt feeders which supply step-down transformers for the lighting load. The only portion of the step-down substation common to both the lighting and the power system is the primary switch, transformer, and main secondary circuit breaker. This is referred to as the basic substation, the installed cost of which is shown in curve *A*, Figure 6. Since other studies have shown the most economical size substation to be 750 to 1,000 kva, an average figure of $7.50 per kilovolt-ampere has been selected from curve *A* to represent the basic substation cost for the combined light and power system.

The 460-volt secondary feeder circuit breakers for the lighting system have been chosen with 25,000-ampere interrupting rating (large enough for 1,500-kva 480-volt 5.5 per cent impedance transformers). The load per feeder is maintained at 100 kva. On this basis the assumed installed cost of the secondary feeder circuit breakers is $5.40 per kilovolt-ampere.

The secondary feeder layout of Figure 9 is used to determine the length of cable for a 100-kva circuit. The 3-conductor number 1 interlocked-armor cable has an assumed installed cost of 90 cents per foot or $3.55 per kilovolt-ampere. Each secondary feeder connects directly to four step-down dry type transformers.

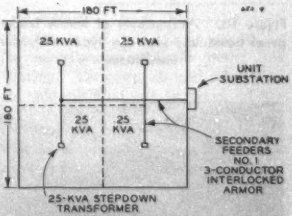


Figure 9. Diagram for determining length of secondary feeder serving 425-kva load areas—system *B*

Total length of secondary feeder cable approximately 315 feet

Use of Small Dry Type Transformers

Because they are the largest single-phase 480–240–120-volt transformer of standard design which can be used and the secondary short-circuit currents kept within 5,000 amperes, the interrupting rating of the circuit breakers in the panel boards, 25-kva transformers were chosen. Taps may be used in the 480-volt winding of these transformers to compensate for transformer voltage drop when necessary.

Separate 460-volt feeders are assumed to be used for serving lighting load only. There are many more outages on power feeders than on lighting feeders because of the greater number of changes made in power feeders. Furthermore, the power feeders may have more voltage drop due to fluctuating loads. Hence, separate lighting feeders often are used for greater reliability and to reduce voltage drop.

A typical outline of an installation of a dry type transformer and a panel board is shown in Figure 10. The installation view in Figure 11 shows two small dry type transformers and panel boards, one for the general area lights and one for miscellaneous 120-volt power.

Switches or circuit breakers are not used ahead of the dry type transformers on the lighting feeder, because the secondary feeder circuit breaker at the unit substation will provide adequate short-circuit

protection for these transformers. Since the lighting load is constant, it is assumed that overload protection is not required. However, should these transformers be connected to heavy power feeders, individual air circuit breakers should be used ahead of each transformer for protecting the transformer under short-circuit conditions and due to overload. The main circuit breaker at the unit substation will afford practically no protection for a small dry type transformer connected to a heavy power feeder.

There is a negligible difference in the cost of dry type step-down transformers and panel boards for various single-phase and 3-phase combinations of transformers and various ballast voltages—that is, 118, 208 volts, and so forth. Therefore, the selection between single-phase and 3-phase banks of small dry type step-down transformers is dependent upon local conditions.

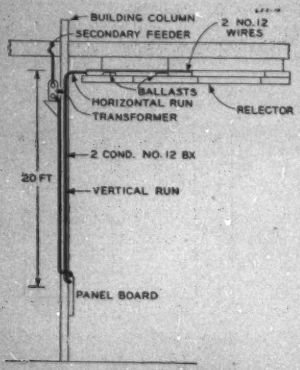


Figure 10. Arrangement of branch feeder panel board and small dry type transformer installations

Selection of Ballast Voltage for System B

The elements of system *B* considered thus far have the same cost regardless of ballast voltage. There are several different ballast voltages which may be selected—namely, 118, 208, 230, or 260 volts. To simplify the selection of ballast voltage, the cost of the items which are affected by ballast voltage are summarized in Table I. There is a slight saving in branch wiring for the higher voltages, but, as pointed out previously, the saving may largely disappear, depending upon local conditions. Hence, to have uniform ballast rating throughout the plant when using system *B*, many operators will use 120 volts, even though there is slightly higher branch circuit wiring cost for that voltage. However, the cost of branch wiring should be studied on each particular job to see if there is any substantial economic benefit to be gained from ballast voltages higher than 118 volts.

The total cost of system *B* is

$ 7.50	Basic substation
5.40	Secondary circuit breakers
3.55	Secondary cable
23.50	Step-down transformers, panel boards, branch circuit wiring, line 3, Table I
$39.95	

per kilovolt-ampere of lighting demand.

Using 230-volt ballast instead of 118-volt ballast would, according to the figures of Table I, reduce the cost of system *B* to

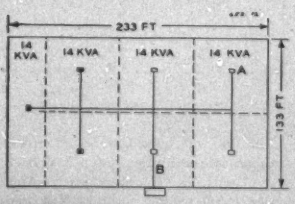


Figure 12 (above). Diagram for determining length of second feeders to serve 7 14-kva load areas, 260-volt fluorescent lamp ballasts—system C

Total length of secondary feeder cable approximately 417 feet
A—Motor starter used as switch for lighting circuit
B—Secondary feeder number 1 3-conductor and neutral interlocked armor cable

Figure 11 (left). Installation view of two panel boards and two small dry type transformers on a building column

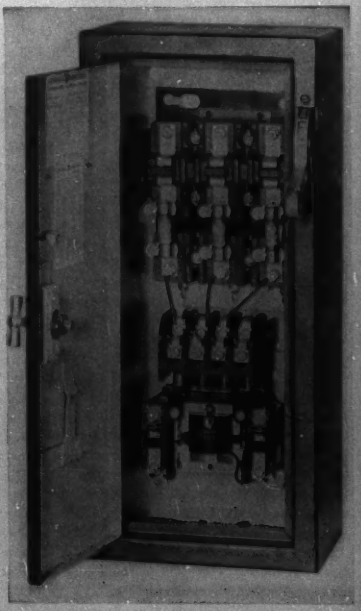


Figure 13. Typical fused combination motor starter used for switching 265-volt fluorescent light circuits—system C

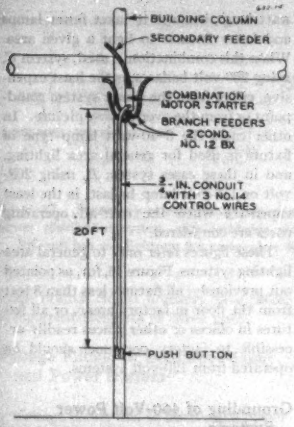


Figure 14. Typical mounting arrangement of fused combination motor starter for switching 265-volt fluorescent light circuits—system C

$36.20 per kilovolt-ampere of lighting demand.

System C—Combined Light and Power Substation, Figure 3

This system is similar to system *B*, Figure 2, except that the fluorescent lamp ballasts are rated 260 volt, and the power system substation is rated 480Y–277 volt, 3 phase with grounded neutral. Several large aircraft assembly plants built at the start of the war used this system for supplying fluorescent lighting loads for general area illumination. It also has been used in many other types of plants since that time. The reason for using this system in the aircraft plants was to save material and not to save money. However, the economic considerations now are more important than material considerations; hence, that system is being reevaluated on the basis of economics.

The substation and secondary feeder circuit breaker costs are the same as for the system *B*, that is, $7.50 and $5.40 per kilovolt-ampere, respectively.

The secondary feeder cost is higher than for system *B*, because a greater length is required to reach the smaller load areas, Figure 12, and because 4-conductor cable is used for the lighting feeders (3-conductor cable for the power feeders). The secondary cable cost is assumed at $1 per foot or $5.20 per kilovolt-ampere.

The branch circuits for the lighting load may be controlled by a 3-pole size 1 fused combination motor starter (for application on circuits with 50,000-ampere available short-circuit current) with three thermal overload elements, Figure 13. Three branch circuits at 265 volts phase to neutral are taken from each motor starter. Since these circuits are limited to about 20 amperes, the lighting load per motor starter is limited to about 14 kva. A typical method of installing a motor starter for this service is shown in Figure 14, where the motor starter is mounted up on the column at the same level as the lights, so that the branch circuits do not have to be run up and down the column. The push button may be located at any convenient spot. The motor starters and push buttons are assumed to cost $3.85 per kilovolt-ampere installed and wired (installation $1 per kilovolt-ampere).

The branch circuit wiring cost, Figure 15, is assumed at $1 per kilovolt-ampere.

The total cost of system *C* as described is

$ 7.50	Basic substation
5.40	Secondary feeder circuit breaker
5.20	Secondary feeder cable
3.85	Controller
1.00	Branch wiring
$22.95	

per kilovolt-ampere of lighting demand.

In some plants now using 260-volt fluorescent ballasts panel boards have been used instead of combination fused motor starters for switching lighting circuits. That substitution reduces the secondary feeder cable required and increases the expense for panel boards and branch wiring. If panel boards with 25 kva of load per board are used, the cost of system *C* is

$ 7.50	Basic substation
5.40	Secondary feeder circuit breakers
3.95	Secondary cable
4.85	Panel boards
2.50	Branch wiring
$24.20	

per kilovolt-ampere of lighting demand.

Short-Circuit Currents

Some operators have objected to system *C* at first glance because of the high short-circuit currents of the power system being available on the lighting circuits. The short-circuit currents on the lighting system are actually very low when the fused combination motor starter is used for controlling the light circuits. The fuses in the motor starter are decidedly current limiting in their action. The three thermal overload elements have a very high impedance and limit the current to even lower values than the fuses would without the thermal elements. The combined effect is to allow not more than about 3,000-ampere peak short-circuit current to flow for a fault in the lighting system, even though the available short-circuit current on the 460-volt power system may be as high as 50,000 rms amperes. To get proper performance of the fused combination motor starter, it is necessary to use not larger than 20-ampere fuses and to have the three thermal overload elements in place in the starter.

The panel board circuit breakers have no current-limiting action; therefore, they allow larger short-circuit currents to appear on the lighting system. However, the application of panel board circuit breakers may allow no higher short-circuit currents to flow in this system than in system *A*, which also is supplied directly from larger transformers. Panel board circuit breakers have the same limitations for application in system *C* as application in system *A* relative to their short-circuit rating.

Other Than General Area Lighting

In systems *A* and *B* 120 volts are available for general area lighting, as well as for miscellaneous 120-volt power and lighting. Therefore, all load other than the 460-volt load can be taken off the same circuits in those two systems.

With system *C* 260-volt ballasts should be used only in fixtures for general factory area lighting. These fixtures must be more than 8 feet from the floor and must not have individual switches mounted in the fixtures. The National Electric Code requires that all lighting for offices, individual benches, machines, and so forth should be operated at 120 volts. Since there is always some load of this nature around any plant, it is necessary to obtain the power for that load from the 460-

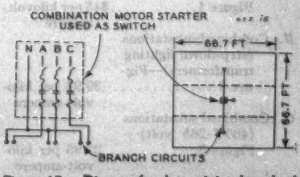


Figure 15. Diagram for determining length of branch circuits for 14-kva load area for system C

Branch circuits are number 12 2-conductor BX wire
Total length of branch circuit 45 feet

Figure 16. A fluorescent lighting installation for general area illumination

volt feeders of system *C*. This can be obtained just as in the case of system *B* with small step-down, dry type transformers as shown to the right of Figure 3. If these transformers are connected to heavy 480-volt feeders, the same precautions should be used in protecting the small transformers as outlined under system *B*.

It is believed that no sacrifice in safety is made with the higher-voltage fluorescent ballasts for the general area fluorescent lighting system, because the lamps and starter voltages are essentially the same, regardless of the voltage rating of the ballast. When the ballasts are changed, the circuit to which the ballasts are connected should be de-energized regardless of the circuit voltage.

Summary of Economic Comparison

Representative first costs of systems *A*, *B*, and *C* are

A..Separate light and power substation, 208Y–120 volt—Figure 1	$45 per kilovolt-ampere
B..Combined substations (step-down lighting transformers)—Figure 2	39.95 per kilovolt-ampere
C..Combined substations (460Y–265 volt)—Figure 3	22.95 per kilovolt-ampere

On the basis of system *A* being 100 per cent, system *B* costs only 89 per cent as much, and system *C* only 51 per cent as much. The savings of the combined light and power system will justify the selection of this system where the total 120-volt load is as high as 50 per cent of the total load at 600 volts or less.

This general comparison also will hold true where incandescent lamps are used throughout, or where other types of gaseous discharge lamps are employed. The ballast for certain types of mercury vapor lamps may be operated from 460-volt circuits.

Although cost comparisons of fluorescent lighting systems are beyond the scope of this paper, it is well to point out that the afore-mentioned figures must be considered in relation to the specific fluorescent lamp layout. The first cost of the power system is small compared with the first cost of the lighting fixtures. The carrying charges on the capital investment of the power system is small compared with the operating cost of the lighting system. Taking all those factors into account, some general guides as to over-all costs of power systems and the lighting fixture system are given in Table III.

Table III shows that even in over-all system cost, combined power and light systems are less expensive than system *A* using separate substations. System *A* does not appear once in the tabulation.

The choice between system *B* and system *C* depends, if one looks at the over-all picture, upon the type of fluorescent lighting fixture used.

For general illumination of very large areas, such as the general working area of a factory, many operators prefer the 100-watt lamp, because it takes fewer lamps and fewer fixtures to light a given area. When this combination is used, system *C*, using 260-volt ballasts, is the least expensive, either from the power system standpoint or from the over-all cost picture. In other cases the 3–40-watt lamp type of fixture is used for general area lighting, and in these cases system *B*, using 208-volt or 118-volt lamp ballast, is the least expensive when the over-all operating costs are considered.

These figures refer only to general area lighting systems, Figure 16, for, as pointed out previously, all fixtures less than 8 feet from the floor in factory areas, or all fixtures in offices or other places readily accessible to factory personnel should be operated from 120-volt systems.

Grounding of 460-Volt Power Systems

The 460Y–265-volt system must have the neutral grounded to accommodate 260-volt lighting fixtures. While some operators who have not had experience with 460-volt grounded Y systems may object to grounding, there are many advantages to having the system neutral grounded, even though 260-volt lighting fixtures may not be used. The biggest single advantage of grounding any power system is immediate isolation of a ground fault before it develops into a double line to ground fault, tripping out a considerable portion of the load.

Grounding of the 460-volt system neutral does not necessitate three thermal overload elements (1940 National Electric Code) in the motor starter for motor circuits. The thermal overload elements are for protection of the motor against overloading and not for short-circuit protection. It does require that all three

Table III

Type of Fixture	*Ballast Voltage	**Type of System With Lowest Cost: First Cost	Operating Cost	Annual Cost
3–40 watt	208	*B*	*B*	*B*
3–40 watt	118	*B*	*B*	*B*
3–40 watt	260	*C*	*C*	*C*
2–40 watt	260	*C*	*C*	*C*
2–40 watt	208	*B*	*B*	*B*
2–40 watt	118	*B*	*B*	*B*
2–100 watt	260	*C*	*C*	*C*
2–100 watt	118	*B*	*B*	*B*
2–100 watt	208	*B*	*B*	*B*

* Voltages are in order of cost, the top representing the least expensive combination and the bottom the most expensive combination for each particular type fixture.

** Includes capital investment in power system, lighting fixtures, cleaning and maintenance, energy cost, and so forth.

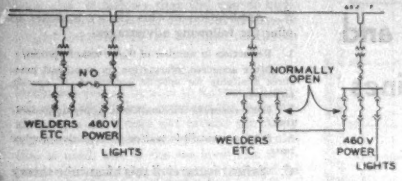


Figure 17. Secondary selective arrangement of load center power distribution system with resistance welders on one 460-volt bus and lights on the companion 460-volt bus

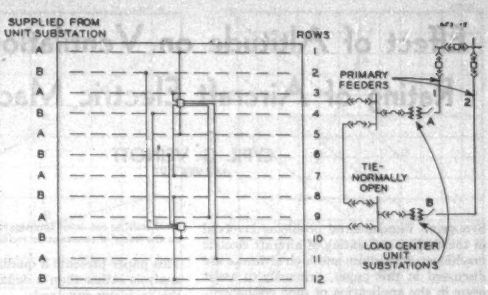


Figure 18. Secondary selective arrangement of load center power distribution system with overlapping areas of lights supplied for different substation busses to prevent complete loss of light should one bus be de-energized

phase branch circuit breakers have three overcurrent elements or three fuses.

Voltage Flicker of Combined Light and Power System

Voltage flicker due to fluctuating power loads will not cause objectionable light flicker in the average factory. Large resistance welders, or large motors which start frequently, should not be connected to the 460-volt bus that serves the plant lighting. Resistance welders are being used in increasing quantities in manufacturing plants, particularly in those that fabricate metal products. In many larger plants employing load center power distribution systems, the welders are connected to a separate transformer which supplies nothing but welding load. In these plants there is no problem of lamp flicker due to resistance welders, unless the plant is supplied by a very weak primary system, in which case the flicker problem will be essentially the same whether or not combined light and power systems are used.

In manufacturing plants where the total resistance welder load is not sufficient to justify separate welding transformers or where there are no exceptionally large welders, the secondary selective arrangement of the load center distribution system may be used, with one of the two substations (Figure 17) for general power load and resistance welders and the other for combined light and power. During normal operation the two substation busses are not in parallel, and the flicker on the bus to which the welders are connected will not affect the lights connected to the other bus. When during an emergency one of the primary feeders or one of the transformers is out of service, the busses may be paralleled, and during that emergency period the flicker may be noticeable. In general there has been no difficulty with combined light and power systems where the principles mentioned have been followed.

Increased Reliability of Lighting Circuits

With any of the systems discussed in this paper, consideration should be given to overlapping the area fed by one substation, so that an outage on that substation will not cause complete outage of lamps in any one area. One method of accomplishing increased reliability economically with the secondary selective load center power system is shown in Figure 18.

Small plants with demands of 500 to 1,500 kva usually require only one substation. It has been common practice to install a power transformer bank and a lighting transformer bank. The welders and power load are connected to the larger bank, and the lights to the smaller one. By using the arrangement shown in Figure 18 with two transformers equivalent in total kilovolt-amperes to the lighting plus the power demand, considerable increase in service reliability can be obtained without incurring objectionable flicker from the welders. With two transformers of equal size, both stepping down to 460 volts, the plant may be kept in at least partial operation with lights and major power apparatus in service with one transformer de-energized. Where separate lighting and power banks are used, this cannot be done. Increased service reliability for the same reason can be obtained in larger plants by using the secondary selective system with substations in pairs, both stepping down to 460 volts, instead of individual light and power substations scattered through the working area.

Effect of Altitude on Ventilation and Rating of Aircraft Electric Machines

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MEMBER AIEE

Synopsis: Fundamental problems involved in the cooling and rating of aircraft electric machinery at medium and high altitudes are discussed in this paper, primarily to assist users in the application of such equipment, and to assist builders in designing equipment to meet the requirements. In addition flight tests are reported which confirm in part the blast-tube theory developed in a previous paper. For blast-cooled generators, an equation has been developed to show the maximum permissible output in terms of entering-air temperature and density, ramming-head pressure, and winding temperature. For motors curves of total winding temperature at rated load have been plotted as a function of altitude; these curves were plotted for selected values of sea-level temperature rise. Specific conclusions are drawn as to:

1. Permissible generator output as a function of altitude and sea-level rise.
2. Limiting sea-level temperature rises for motors on the basis of constant or reduced life at altitude.

This paper presents a qualitative method of analysis rather than a definitive solution of the problems involved.

ONE of the first steps to be taken when applying a blast-cooled generator to any given airplane is to determine the amount of pressure head available for each significant flight condition. By comparing this head with the pressure on which the machine's rating is based, the application engineer can determine approximately what output can be obtained without danger of overheating the generator. One object of this paper is to demonstrate a method for readily determining the available pressure head without as many flight tests as now commonly taken. A knowledge of this pressure head under more conditions makes it possible to apply generators more accurately and to obtain more representative altitude-chamber data.

Altitude rating of generators is approached from the standpoint of determining the load required at all altitudes to give the same total winding temperature. This approach leads to the permissible output of the generator for constant insulation life at all altitudes.

Altitude rating of motors has been approached from a somewhat different angle. Load and speed are assumed constant, and relationships are established between sea-level rise and total winding temperature at altitude. By assuming that insulation life halves with each 10-degree-centigrade increase in temperature, the effect of sea-level temperature rise on the altitude life of insulation was determined and plotted in Figure 1, which was derived from Figure 8.

It must be emphasized, however, that generator outputs above full load well may be limited by commutation or by excitation power. This paper is concerned only with the influence of temperature on rating and starts with a study of blast-cooling phenomena.

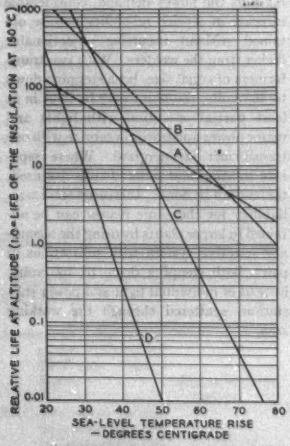

Figure 1. Effect of sea-level temperature rise of fan-cooled motors, open or enclosed, upon the insulation life at different altitudes (derived from Figure 8)

A—At sea level +60 degrees centigrade ambient temperature
B—At 20,000 feet +10 degrees centigrade ambient temperature
C—At 40,000 feet −40 degrees centigrade ambient temperature
D—At 50,000 feet −40 degrees centigrade ambient temperature

Summary and Conclusions

A. A theory of blast-tube cooling has been developed and confirmed in part by actual flight tests.

B. Application of this theory appears to offer the following advantages:

1. Reduction in number of flight tests required.
2. More accurate information on ram-head pressures available for specific generators in specific airplanes.
3. More accurate information in applying generators.
4. More accurate information for altitude-chamber tests.

C. Salient features of this blast-tube theory are:

1. Air flow is measured in terms of velocity head.
2. Blast-tube characteristics can be represented by two factors:
(a). Closed-end pressure, analogous to open-circuit voltage of a battery.
(b). Air-flow resistance, analogous to internal resistance of a battery.
3. A generator without a fan has air-flow resistance only.
4. A generator with internal fan has air-flow resistance plus internal pressure.
5. Calculations of air flow (in terms of velocity head) are analogous to, and as simple as, the application of Ohm's law.
6. Closed-end pressure of a blast tube is independent of altitude, but for any given airplane is approximately proportional to the square of the indicated air speed.
7. Air-flow resistance of the blast tube, or generator, is independent of altitude, and independent of the indicated air speed.
8. Total pressure head on a blast-cooled generator, at any given indicated air speed, is substantially independent of altitude, unless the generator has an internal fan.

D. Generally speaking, the permissible output of a blast-cooled generator varies with the ramming-head pressure: above full load, the output tends to vary as the fourth root of the pressure; below full load, the output tends to vary as the square root of the pressure.

E. Altitude adversely affects the rating of the following classes of machines in the order given:

1. Fan-cooled machines (open or enclosed)—most affected.
2. Blast-cooled machines.
3. Totally-enclosed machines (not fan-cooled)—least affected.

F. Increase in altitude has its greatest effect on the rating of all classes of electric equipment in the isothermal stratosphere which begins, according to Army maximum standards, at 40,000 feet.

G. As a rule the higher the sea-level temperature rise, the more the output is affected adversely by increase in altitude. Conversely, the higher the specified maximum altitude, the lower must be the sea-level rise.

H. Since apparatus with a high sea-level temperature rise is affected more adversely by altitude than apparatus with a low sea-

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level rise, it follows that the use of high-temperature insulation offers less promise of weight reduction as the specified maximum altitude is raised.

I. Blast-cooled generators with class *A* insulation should be able to deliver full output up to 49,000 feet, provided the entering-air temperature does not exceed the Army maximum specification. If class *B* insulation is used, and if the sea-level rise is increased accordingly, full output should be expected only up to 40,000 feet.

J. Fan-cooled generators generally are not practicable for altitudes above 20,000 feet.

K. Fan-cooled motors which are expected to deliver full rated output with full life expectancy at 40,000 feet should have a sea-level temperature rise not exceeding:

1. 50 degrees centigrade if class *A* insulation is used.
2. 56 degrees centigrade if class *B* insulation is used.

These figures are based on an ambient temperature per Army maximum specification and full life expectancy at altitude. Considerable reduction in life expectancy at altitude does not increase the permissible sea-level rise so much as might be supposed. See Figure 1.

L. Fan-cooled motors which are expected to deliver full rated output with full life expectancy at 50,000 feet should have a sea-level temperature rise not exceeding:

1. 33 degrees centigrade if class *A* insulation is used.
2. 37 degrees centigrade if class *B* insulation is used.

These figures are likewise based on an ambient temperature per Army maximum specification and full life at altitude. Reduction of altitude life for changes in sea-level rise is shown in Figure 1.

M. Fan-cooled motors designed for a maximum altitude of 50,000 feet may be as much as 20 per cent heavier than comparable motors designed for 40,000 feet, unless the life at top altitude is considerably reduced.

N. Enclosed motors, and static apparatus cooled by radiation and free convection, can be permitted a sea-level rise of 70 degrees centigrade for class *A* insulation, or 90 degrees centigrade for class *B* insulation; such apparatus should be satisfactory for all altitudes up to 50,000 feet, provided the ambient temperature does not exceed the Army maximum value.

Air-Flow Mechanics of Blast-Tube Cooling

Heretofore the only method available for determining the total pressure head available for a particular blast-cooled generator has been by an actual flight test. This method has the advantage of being simple and direct. But it has the important disadvantage of requiring a flight test for every generator–airplane combination to be studied. Because this procedure would require too many flight tests, there is an unfortunate tendency to take a mere guess at the pressure. A somewhat different approach to this problem was presented to AIEE in 1944.[1] Since then some flight tests have been made which tend to confirm the practicability of this approach. The method therein presented is summarized in the following paragraphs, together with flight-test data.

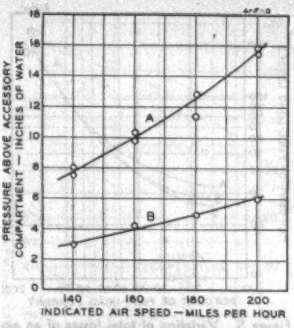

Figure 2. Flight-test measurements of the total pressure head available at the generator end of the blast tube with no generator

Four-engine bomber, number 2 nacelle
A—Closed-end readings
B—Open-end readings
Altitude: 5,000 feet

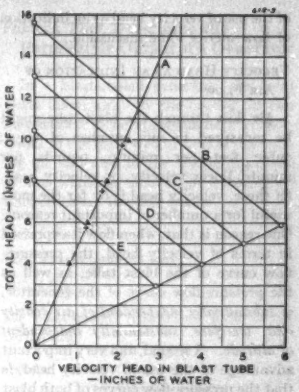

Figure 3. Pressure-flow curves of blast tubes and aircraft generators

Two-inch-diameter blast tube
O Blast-tube pressure-flow curves determined by flight tests without generators
Δ Generator pressure-flow curve determined by laboratory tests
\+ Generator pressures measured on flight test
A—Pressure-flow curve of a representative generator
B—Blast-tube pressure-flow curves at 200-miles-per-hour indicated air speed
C—At 180-miles-per-hour indicated air speed
D—At 160-miles-per-hour indicated air speed
E—At 140-miles-per-hour indicated air speed

The underlying philosophy of this method is to measure, by means of a flight test, the pressure-flow curve of the blast tube itself; that is, a curve of total pressure head available versus the quantity of air taken from the tube. Similarly, by means of a laboratory test the pressure-flow curve of the generator under consideration is determined by measuring the pressure required to force different amounts of air through the generator. When these two pressure-flow curves are plotted on the same curve sheet, the point of intersection automatically gives the pressure across the generator as well as the amount of air flow. Likewise, the pressure-flow curve for any other generator then can be determined and plotted in order to determine the pressure and amount of air available for that particular generator *without an additional flight test*. But the pressure and amount of air can be computed even more easily by making use of the equations of Figure 4 which have been arranged in the form of simple electric-circuit equations; use of these equations is explained more fully later.

Extremely significant to this method is the factor selected as an indication of "quantity of air," namely, velocity head. Because of its importance the significance

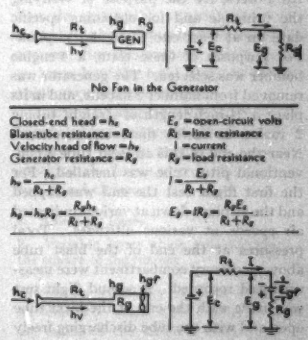
GEN
No Fan in the Generator
Closed-end head = h_c
Blast-tube resistance = R_t
Velocity head of flow = h_v
Generator resistance = R_g
E_o = open-circuit volts
R_l = line resistance
I = current
R_g = load resistance
$h_v = \frac{h_c}{R_t + R_g}$
$h_g = h_v R_g = \frac{R_g h_c}{R_t + R_g}$
$I = \frac{E_o}{R_l + R_g}$
$E_g = IR_g = \frac{R_g E_o}{R_l + R_g}$
With Internal Fan in the Generator
$h_v = \frac{h_c + h_{gf}}{R_t + R_g}$
$h_g = h_v R_g - h_{gf} = \frac{R_g h_c - R_t h_{gf}}{R_t + R_g}$
$I = \frac{E_o + E_{of}}{R_l + R_g}$
$E_g = IR_g - E_{gf} = \frac{R_g E_o - R_l E_{gf}}{R_l + R_g}$
Note: If h_g is —, generator fan helps overcome R_t as well as R_g, and more air would flow through generator if blast tube were removed from generator.
Note: If E_g is —, E_{gf} helps overcome R_l as well as R_g, and more current would flow if terminals E_g were short-circuited.

Figure 4. Electric circuit analogue

of the use of velocity head as an indication of flow merits some discussion.

Velocity Head as an Indication of Air Flow

Air flow through the blast-tube might be measured in any number of ways: cubic feet per minute, pounds per minute, linear velocity, or velocity head. Of these, velocity head is by far the most useful for a number of important reasons. One reason is that, when flow is expressed in terms of velocity head, the pressure-flow curve of the blast tube, as well as the pressure-flow curve of the generator, *is substantially independant of air density and, therefore, substantially independent of altitude.* A second, and very important advantage of the use of velocity head, is that the pressure-flow curves of both blast tubes and generators alike become straight lines. Now, since the pressure-flow curve of a blast tube is a straight line, it is necessary to measure only two points on it. (For a generator pressure-flow curve, only a single point is needed.) These two points can be determined most conveniently by measuring the open-end and closed-end pressures, as pointed out in a previous paper.[1]

Flight Tests to Check Basic Theory of Blast-Tube Cooling

Flight tests were made at Vandalia, Ohio, with the co-operation of the Army Air Forces, for the purpose of verifying the principle and for obtaining specific data on at least one particular airplane. For purposes of these tests, a 4-engine bomber was selected. The generator was removed from number 2 nacelle, and in its place a 24-inch length of straight tubing 2 inches in inside diameter was used. Near the end of this straight tube a conventional pitot tube was installed. For the first flight test the end was capped and the airplane flown at various indicated air speeds at various altitudes. Total pressures at the end of the blast tube above accessory compartment were measured and recorded. A second flight test was made with the end of the blast tube open and with the tube discharging freely into the accessory compartment. It was found, as expected, that the total pressure above the accessory compartment, whether the end was closed or open, depended upon the indicated air speed but was substantially independent of the altitude. The open- and closed-end readings which were taken at an altitude of 5,000 feet have been plotted in Figure 2. Two additional similar curves were taken flying at altitudes of 10,000 and 15,000 feet, respectively; the resulting data

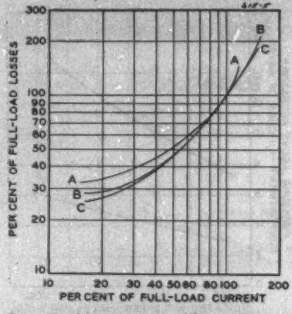

Figure 5. Variation of total losses of an aircraft generator as a function of output amperes and rpm

A—At 4,000 rpm
B—At 6,000 rpm
C—At 8,000 rpm

Generator rating: 9 kw, 30 volts, 300 amperes, 4,400–8,000 rpm

were nearly identical with those of Figure 2.

From the open- and closed-end readings taken on the flight tests, pressure-flow curves of the blast tube were plotted for different indicated air speeds; these curves are given in Figure 3. (In Figure 3 each point is the average of several readings taken at three different altitudes.) Next the generator was set up in the laboratory, and total pressure heads of 4, 6, 8, and 10 inches, respectively, were impressed on the generator. Temperature of the entering air was held at various values from −5 degrees centigrade to +20 degrees centigrade, and the pressure altitude of the incoming air was varied from 5,000 to 15,000 feet. Velocity heads of the entering air were measured and averaged for each different applied pressure. In Figure 3 velocity head in the blast tube has been plotted against total pressure head applied, obtaining the pressure-flow curve of this particular generator. (Ordinarily it is sufficient to measure the flow for a given pressure at ground-level conditions; entering-air temperature and atmospheric pressure have relatively little effect in this measurement, because velocity head is used as the measure of flow.)

Points of intersection of the pressure-flow curve of the generator with the respective pressure-flow curves of the blast tube give the pressures to be expected upon that generator in flight; these intersection points also give the velocity heads of air flowing through the blast tube and generator. As a check, this generator was installed and flight tested; observed values of generator head are indicated by crosses on the curve. The agreement is remarkable and demonstrates that the theory is workable.

Electric-Circuit Analogue an Aid to Blast-Tube Calculations

Instead of actually plotting pressure-flow curves and determining the point of intersection, it is much simpler to calculate the point of intersection. For this purpose one concept needs to be introduced—that of air-flow resistance—which is defined as the ratio of the lost head to the velocity head. This concept makes air-flow resistance comparable to ohmic resistance in an electric circuit, which is the ratio of the voltage drop to the current. In a blast tube, however, a note of caution must be given: in any given blast-tube system, all velocity heads must be referred to the same diameter of tube. Air-flow resistance of the blast tube is

$$R_t = \frac{h_c - h_o}{h_o} \qquad (1)$$

Air-flow resistance of a generator without a fan is

$$R_g = \frac{h_g}{h_{vg}} \qquad (2)$$

A tube resistance, R_t, of 4.0 means that the head loss in the tube is equal to 4.0 velocity heads. Thus, air-flow resistance, as defined and used herein, does have a definite physical significance.

Just as the characteristics of a battery can be expressed in terms of open-circuit voltage and internal resistance, so can the pressure-flow curve of a blast tube be ex-

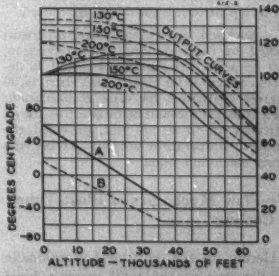

Figure 6. Influence of altitude on the permissible continuous outputs of blast-cooled generators

Calculations are based on the constant winding temperatures shown on the respective curves
—— Output based on Army maximum ambient temperatures
– – Output based on NACA ambient temperatures

A—Army maximum ambient temperature
B—NACA ambient temperature

pressed in terms of closed-end pressure and tube resistance. The blast-tube pressure-flow curves of Figure 3 are represented in Table I. It will be noted that the open-end pressures are given; these were used in calculating the tube resistance. It is particularly gratifying to note that the tube resistance does not vary with altitude, nor does it vary to any significant extent with indicated air speed. There is no particular reason why it should vary with altitude or with air speed, and the slight discrepancies noted may be due to test errors.

Equations for calculating the pressure head available for any generator of known air-flow resistance are given in Figure 4, where they are compared with exactly analogous equations for a simple d-c series circuit. The analogy is of great assistance in remembering the equations. Extension of this theory to include generators with an internal fan was a natural development of the electric-circuit analogue.

Generators With Internal Fan

Internal fans alone usually do not provide enough ventilation to make generators satisfactory above 20,000 feet. However, use of an internal fan does provide some ground power capacity and, when used in conjunction with blast cooling, has the general effect of increasing the air flow. Let the pressure of the internal fan be denoted by h_{gf}. This pressure is proportional to the square of the speed and to the first power of the air density; it can be represented by the equation

$$h_{gf} = F_g \times \left(\frac{N}{1{,}000}\right)^2 \times \frac{\rho_A}{\rho_0} \qquad (3)$$

where F_g is an empirical constant. Physically, F_g is the pressure developed by the fan at sea-level air density at 1,000 revolutions per minute. This constant F_g might be measured by blocking either the inlet or the outlet and measuring the pressure at the blocked end of the generator; readings should be taken at different speeds and the constant F_g determined from equation 3.

Air-flow resistance of a fan-cooled generator can be determined by applying a known pressure head h_g and measuring the velocity head h_{vg} of the entering air. The air-flow resistance is then

$$R_g = \frac{h_g + h_{gf}}{h_{vg}} \qquad (4)$$

Velocity head of the air flowing into a fan-cooled generator and pressure head across it can be computed by using the equations of Figure 4. It is to be noted that the same constants of the blast tube apply whether the generator has an internal fan or not. However, since the pressure of the generator fan does vary with altitude, the pressure drop across the generator also will vary with altitude. If there is no internal fan in the generator, the pressure across the generator will not vary with altitude. If there is an internal fan, the general effect of altitude will be to reduce the velocity-head flow and to increase the pressure across the generator.

Of interest is the case of the blast-cooled generator with internal fan operating on the ground with no ram-head pressure applied. From the equations of Figure 4, the air flow through the generator and blast-tube combination and the pressure across the generator (necessarily negative) readily can be computed. The cooling effect, of course, is determined by the weight of air flowing, rather than by the pressure head.

Table I. Blast-Tube Characteristics Obtained From Flight Tests

Indicated Air Speed	Open-End Pressure, h_o	Closed-End Pressure, h_c	Tube Resistance, R_t
140	2.9	8.0	1.76
160	4.0	10.4	1.60
180	5.0	13.0	1.60
200	5.9	15.6	1.64

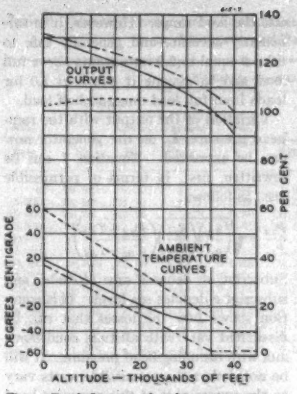

Figure 7. Influence of ambient temperatures on the permissible continuous output of a blast-cooled generator at various altitudes

Generator rating: 9 kw, 300 amperes, 30 volts

Winding temperature: 150 degrees centigrade

- - - NACA temperature

——— Actual ambient temperatures used in laboratory tests

----- Army maximum temperatures

Factors That Determine the Permissible Output of a Generator

In a blast-cooled generator the total watts taken away by the cooling air can be assumed to be approximately proportional to the total weight flow of the cooling air and also to the temperature rise of the windings above the entering-air temperature. In other words

$$P_l \propto W(T_s - T_a) \qquad (5)^*$$

but, for the general case,

$$W \propto \sqrt{\rho h_v} \qquad (6)$$

for blast-cooled generators with no internal fan

$$h_v \propto h_g$$

so that we may assume

$$W \propto \sqrt{\rho h_g} \qquad (6a)$$

therefore,

$$P_l = C_1 \sqrt{\rho h_g}(T_s - T_a) \qquad (7)$$

Equation 7 is of inestimable value in evaluating altitude performance. It shows how the heat-dissipating capacity of the cooling air depends upon:

1. Air density.
2. Pressure head across the generator.
3. Winding temperature.
4. Ambient temperature.

Of even greater interest to the user of generators, however, is a knowledge of how the permissible output, rather than permissible loss, depends upon these same factors. For this purpose, it is necessary to know how the total losses in the machine vary with the output.

There is no single fixed relationship between output and losses which holds for all aircraft electric machines. Generally speaking the losses may be divided into two broad classes:

1. Constant losses.
2. Variable losses which generally vary as the square of the current.

Maximum efficiency of the generator is obtained when the constant losses are equal to the variable losses, and, at this point, the efficiency curve is usually quite flat. An efficiency curve flat over a range means that the losses are directly proportional to the output over the same range. Below the maximum-efficiency point they decrease more slowly than the output. How these total losses vary with the current has been plotted in Figure 5 for a typical 9-kw d-c aircraft generator.

* More accurately, W should have an exponent slightly less than 1.0, but for the purposes of this paper the gain in accuracy in using a decimal exponent here is hardly justifiable.

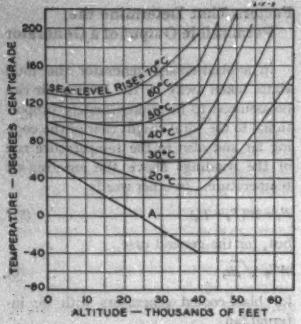

Figure 8. Fan-cooled motors, open or enclosed, effect of altitude on the winding temperature for different values of sea-level rise

Output, losses, and rpm assumed constant
A—Ambient temperature (Army maximum)

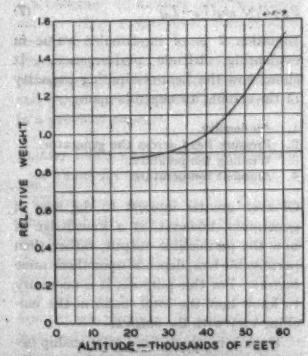

Figure 9. Curve showing approximately how the weight of an open fan-cooled motor is affected by the maximum altitude for which it is designed

Based on Army maximum ambient temperature curve and a motor designed for 40,000-foot altitude as unit weight

It will be noted that the variation of losses with current also is affected by the generator's operating speed, which changes the distribution between the constant and variable losses. It will be observed on this curve that, the higher the load, the faster the losses increase with increase in current. It would be convenient if we could express the losses as a simple function of the load current, such as

$$P_l = C_2 I^{\beta} \tag{8}$$

Unfortunately the value of β, which is the slope of the curve, is not constant throughout the load range. However, it is sufficiently accurate and generally safe to take β equal to 2.0 for outputs above full load and to assume it equal to 1.0 for loads from full load down to half load.

Variation of the output with the ram-head pressure, h_p, on the generator now can be expressed. Equation 7 can be rewritten, first, in terms of permissible loss, as follows:

$$\frac{P_{lA}}{P_{lo}} = \sqrt{\left(\frac{\rho_A}{\rho_o}\right)\left(\frac{h_{pA}}{h_{po}}\right)}\left(\frac{T_{SA}-T_{aA}}{T_{So}-T_{ao}}\right) \tag{9}$$

Subscript A denotes any altitude, and subscript o denotes sea level. This equation shows how the losses that can be dissipated vary with altitude conditions, and with ramming-head pressure. It will be noted that the permissible watts vary as the square root of this ramming-head pressure. This relationship then can be interpreted in terms of current output as follows:

$$\frac{I_A}{I_o} = \left[\sqrt{\left(\frac{\rho_A}{\rho_o}\right)\left(\frac{h_{pA}}{h_{po}}\right)}\left(\frac{T_{SA}-T_{aA}}{T_{So}-T_{ao}}\right)\right]^{1/\beta} \tag{10}$$

When the expression in brackets is greater than unity, β may be taken equal to 2.0. When the expression in brackets is less than unity, β may be taken equal to 1.0. In other words, if the pressure available is less than the rated pressure, the generator should be derated proportionally to the square root of the applied pressure; if the pressure is more than the specified value, the generator could be uprated, so far as overheating is concerned, as the fourth root of the pressure. However, it must be borne in mind that commutation, field excitation, or some limit other than temperature rise may limit the uprating of the generator.

Equation 10 was developed for the most common case of a generator without a fan. To take into account the effect of an internal fan, equation 10 can be written as follows:

$$\frac{I_A}{I_o} = \left[\sqrt{\left(\frac{\rho_A}{\rho_o}\right)\left(\frac{h_{pA}}{h_{po}}\right)}\left(\frac{T_{SA}-T_{aA}}{T_{So}-T_{ao}}\right)\right]^{1/\beta} \tag{10a}$$

In this equation, h_{po} represents the velocity head of the air entering the generator at sea level with rated pressure applied. Theoretically, this equation should be applicable when no ram head is applied; practically, the equation is of rather doubtful value when extended so far because:

1. The β exponent does not hold so well for low values of load, for instance, below 30 per cent.
2. The effect of the rotation of the armature, which is more important under these conditions, is not fully taken into account.

Effect of High Altitude on Output of Blast-Cooled Generators

Factors affecting the rating of a generator at altitude, from the standpoint of winding temperature, are:

1. Density of the cooling air. (See Table II.)
2. Ram-head pressure or h_p; for a blast-cooled generator, this does not vary with altitude.
3. Ambient temperature. In the following analysis this generally was assumed to be as specified by the Army maximum curve (see Figure 6, and Table II), but this may not always be so. Test data are needed on entering-air temperatures of blast-cooled generators.
4. Permissible or assumed temperature of the windings.
5. β, that is, how much the losses vary with the current output.

A general relationship between the foregoing factors is shown in equation 10. In Figure 6 are plotted some curves calculated from this equation. In all of these curves the total winding temperature has been assumed constant at all altitudes. These curves show the influence of altitude on the permissible continuous output of blast-cooled generators. Three different machines were taken for this analysis, having assumed winding temperatures of 130 degrees centigrade, 150 degrees centigrade, and 200 degrees centigrade respectively. This would correspond approximately to class *A* insulation, class *B* insulation, and special high-temperature insulation. It further was assumed that the temperature of the entering air was at Army maximum value, as shown in Figure 6 and Table II, and that the machine had rated temperature rise at sea level. Also, the permis-

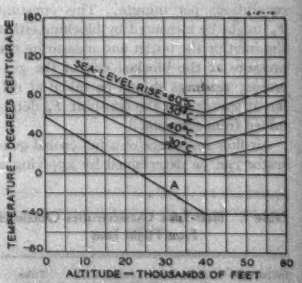

Figure 10. Enclosed motors, effect of altitude on the frame temperature for different values of sea-level rise

Output and losses assumed constant
A—Ambient temperature (Army maximum)

sible outputs of these same machines were computed on the basis of entering-air temperatures equal to National Advisory Committee on Aeronautics ambient temperatures; these temperatures are also shown in Figure 6 and Table II. Some interesting conclusions are deducible from the curves in Figure 6.

If the sea-level temperature rise is not over 70 degrees centigrade, full output rating can be obtained up to 49,000 feet. However, if the machine is designed for a higher sea-level temperature rise, such as 90 degrees centigrade, full rated output can be maintained only up to 42,000 feet. If extra-high-temperature insulation is used that permits the machine to have a sea-level rise of 140 degrees centigrade, full rating can be maintained only up to 20,000 feet. Any given machine can develop more output without overheating in an NACA standard atmosphere than in an Army maximum standard atmosphere, because the former has lower temperatures. This effect is shown in Figure 6 for the three hypothetical machines by plotting the permissible output for both ambient-temperature curves. The difference in output decreases with altitude, especially above 40,000 feet.

Curves shown in Figure 6 should be fairly representative of blast-cooled generators. For purposes of comparison, similar curves, except that they are based on actual tests on a typical aircraft generator, are given in Figure 7. These curves are based on altitude-chamber tests on a 9-kw d-c generator. Actual temperature rises were measured at different altitudes in the chamber, and the three output curves at the top of the sheet were corrected by calculation to correspond to the three different ambient temperature curves shown at the bottom. In making these corrections, it was assumed that temperature rise was directly proportional to watts loss. Permissible watts loss was converted to current output by making use of Figure 5, which applies to the particular generator that was altitude-tested. In general these curves agree with the 150 degrees centigrade curve of Figure 6 with a reasonable degree of accuracy. However, they tend to show that there is some loss in permissible output above 34,000 feet, whereas the theoretical curve of Figure 6 shows full output being maintained up to 42,000 feet.

Effect of Altitude on Aircraft Motors

Permissible loss in an aircraft motor varies with speed as well as with permissible temperature rise and air density. Hence, it is difficult to express the output as a function of altitude because of the variation in speed, particularly in the case of a series motor. Furthermore, for many applications the load imposed on the motor does not vary with altitude, so that the motor has to carry the same load at all altitudes. Therefore a new and somewhat different approach has been used. This approach involves investigating the actual temperatures encountered by the windings at different altitudes, assuming a constant load and a constant speed. However, in some applications, notably fan, the load falls off at altitude, and the speed will increase if a series motor is being used. For the present, however, the following discussion is confined to motors operating at a constant load and a constant speed.

There are two types of motors to be considered: fan-cooled, open or enclosed; and enclosed.

Fan-Cooled Motors (Open or Enclosed)

Temperature-rise tests taken in an altitude chamber on a number of aircraft motors under different conditions showed that the temperature rise was approximately inversely proportional to the density raised to the 0.9 power. By use of this empirical fact, the winding temperature of open fan-cooled aircraft motors has been calculated and plotted in Figure 8 as a function of altitude with sea-level rise as parameter. From these curves a number of interesting conclusions can be deduced:

1. Winding temperatures start to increase sharply above 40,000 feet. For satisfactory performance at high altitude, a comparatively low sea-level temperature rise is essential.

2. Use of high-temperature insulation is not particularly helpful, either in increasing the maximum altitude rating or in reducing the weight by increasing the permissible sea-level rise.

3. For a maximum altitude rating of 40,000 feet, at a maximum ambient temperature of −40 degrees centigrade, the maximum permissible sea-level rise is: for class *A* insulation, 50 degrees centigrade; for class *B* insulation, 56 degrees centigrade.

4. For a maximum altitude rating of 50,000 feet, at a maximum ambient temperature of −40 degrees centigrade, the maximum sea-level rise would be: for class *A* insulation, 33 degrees centigrade; for class *B* insulation, 37 degrees centigrade. Use of a high-temperature insulation which would permit a temperature rise of 140 degrees centigrade (total temperature of 200 degrees centigrade) still would require the motor to have a sea-level rise as low as 46 degrees centigrade.

These conclusions are somewhat pessimistic for motors smaller than 4 inches in diameter, and optimistic for motors larger than this.

Weight is always a matter of primary concern, and it would be interesting to know how the weight of a motor is affected by the maximum altitude at which the motor is intended to operate. Curves in Figure 8 show what the sea-level rise has to be in order not to exceed safe temperatures at any given altitude, but it is not so easy to determine how the weight of the motor is affected by the sea-level temperature rise for which it is designed. However, since it frequently is assumed that weight is proportional to the square root of the output, it seems fairly reasonable to assume that the weight would vary inversely as the square root of the specified sea-level temperature rise. On this assumption, Figure 9 was plotted to show how the weight of an open fan-cooled aircraft motor is affected by the maximum altitude for which the motor is designed. This curve shows that a motor actually designed for 50,000 feet

Table II. Standard Temperatures and Densities of Air for Both National Advisory Committee on Aeronautics and Army Maximum Standards

	NACA Standard Conditions						Army Maximum Conditions				
Altitude, Feet	Pressure, Inches, H_g	Pressure, Centimeters, H_g	Temperature, Degrees Centigrade	Pounds Per Foot, ρ	ρ	$\sqrt{\frac{\rho}{0.07651}}$	Temperature, Degrees Centigrade	Pounds Per Foot, ρ	ρ	
					0.07651	0.07651			0.06617	0.06617
0	29.921	76.00	15	0.07651	1.0000	1.0000	60	0.06617	1.0000	1.0000
5,000	24.89	63.23	5.1	0.06591	0.8615	0.9282	47.5	0.05719	0.8643	0.9297
10,000	20.58	52.26	− 4.8	0.05651	0.7386	0.8594	35.0	0.04921	0.7437	0.8624
15,000	16.88	42.88	−14.7	0.04813	0.6291	0.7932	22.5	0.04207	0.6358	0.7974
20,000	13.75	34.91	−24.6	0.04076	0.5327	0.7299	10.0	0.03578	0.5407	0.7353
25,000	11.10	28.19	−34.5	0.03427	0.4479	0.6693	− 2.5	0.03032	0.4567	0.6758
30,000	8.880	22.56	−44.4	0.02861	0.3739	0.6115	−15.0	0.02535	0.3831	0.6190
35,000	7.036	17.87	−54.3	0.02389	0.3096	0.5564	−37.5	0.02200	0.3325	0.5766
40,000	5.541	14.07	−55.0	0.01872	0.2447	0.4947	−40.0	0.017513	0.2647	0.5144
45,000	4.364	11.08	−55.0	0.01474	0.1927	0.4390	−40.0	0.013793	0.2084	0.4565
50,000	3.436	8.730	−55.0	0.011607	0.15171	0.3895	−40.0	0.01086	0.16412	0.4051
55,000	2.707	6.876	−55.0	0.009143	0.11950	0.3457	−40.0	0.008556	0.1293	0.3596
60,000	2.132	5.415	−55.0	0.007201	0.09412	0.3068	−40.0	0.006738	0.10182	0.3191
65,000	1.679	4.265	−55.0	0.005671	0.07412	0.2723	−40.0	0.005307	0.08020	0.2833

might be as much as 20 per cent heavier than similar motors designed for a maximum altitude of but 40,000 feet.

Enclosed Motors (Not Fan Cooled)

The dissipating capacity of an enclosed motor does not fall off with increase in altitude so fast as that of a fan-cooled motor, primarily because:

1. Watts loss dissipated by radiation is independent of the air density.

2. Watts loss dissipated by natural convection is proportional to the square root of the density. (With forced convection, as in blast-cooled or fan-cooled machines, the watts dissipated are proportional to the first power of density.)

Using a combination of empirical and theoretical data, the frame temperature of a totally enclosed motor has been calculated as a function of altitude, with sea-level temperature rise of the frame as parameter. These curves are given in Figure 10. (It must be borne in mind that the temperature of the winding will be somewhat higher than the frame temperature.) Comparing these curves with those of Figure 8, it readily is concluded that the rating of enclosed motors is not reduced so much at altitude as those of fan-cooled motors. In fact, if a totally enclosed motor is designed for a sea-level rise of 70 degrees centigrade, it should give satisfactory performance at all altitudes from sea level up to well above 60,000 feet. It also appears likely that a motor designed for class *B* insulation with a 90-degree-centigrade temperature rise at sea level would be satisfactory at all altitudes from sea-level up to 50,000 or 60,000 feet.

Summary of Effect of Altitude on Heat Transfer

Generally speaking, the heat generated in an aircraft electric machine may be dissipated in a number of different ways. How altitude conditions affect the amount of heat lost by each of the different components of heat transfer are summarized in the following equations.

Forced convection, blast cooling, without internal fan:*

$$\frac{P_{1A}}{P_{1o}} = \sqrt{\left(\frac{\rho_A}{\rho_o}\right)\left(\frac{h_{tA}}{h_{to}}\right)}\left(\frac{T_{sA}-T_{aA}}{T_{so}-T_{ao}}\right) \qquad (11)$$

Forced convection, fan cooling:

$$\frac{P_{1A}}{P_{1o}} = \frac{\rho_A}{\rho_o} \times \frac{RPM_A}{RPM_o} \times \frac{T_{sA}-T_{aA}}{T_{so}-T_{ao}} \qquad (12)$$

Free convection:

$$\frac{P_{1A}}{P_{1o}} = \sqrt{\left(\frac{\rho_A}{\rho_o}\right)}\left(\frac{T_{sA}-T_{aA}}{T_{so}-T_{ao}}\right)^{1.25} \qquad (13)$$

Radiation:

$$\frac{P_{1A}}{P_{1o}} = \frac{(T_{sA}+273)^4-(T_{aA}+273)^4}{(T_{so}+273)^4-(T_{ao}+273)^4} \qquad (14)$$

Symbols

A = subscript A denotes "at altitude." May be added to any of the following symbols

o = subscript o denotes "at sea level." May be added to any of the following symbols

* If an internal fan is used, substitute h_{sA} and h_{so} for h_{tA} and h_{to}, respectively.

h_c = closed-end pressure of a blast tube above accessory compartment, inches of water

h_o = open-end pressure of a blast tube above accessory compartment, inches of water

h_t = total head across the generator, inches of water

h_v = velocity head of air flowing through blast tube, inches of water

h_{vg} = velocity head of air entering generator, inches of water (equation 4)

h_{sf} = pressure head developed by an internal fan, inches of water

F_p = pressure developed by an internal fan at 1,000 rpm at sea-level air density

N = revolutions per minute

T_o = temperature of exit air, degrees centigrade

T_s = temperature of stator windings, degrees centigrade

T_a = temperature of ambient air or of air entering generator

P_1 = total watts loss carried away by cooling air

W = weight flow of cooling air, pounds per minute

ρ = specific weight of air, pounds per cubic foot

$C_1, C_2, \ldots$ = proportionality constants

β = exponent in equation 8

I_o = current rating of generator at sea-level, amperes

I_A = permissible current output (thermal basis only) at altitude, amperes

References

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2. Altitude Rating of Electric Apparatus, Paul Lebenbaum, Jr. AIEE Transactions, volume 63, 1944, December section, pages 955–60.

Electrical Analogy Methods Applied to Servomechanism Problems

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Synopsis: This paper describes the application of the transient analyzer to the solution of servomechanism problems by the electrical-mechanical analogy method. The analogies for angular position servomechanisms are developed in detail together with the fundamental concepts by which the systems can be defined in terms of dimensionless parameters. This permits the results to be given in dimensionless form suitable for general application. Typical solutions of representative systems are given in the form of transient response curves. These show the response characteristics for suddenly applied constant velocity and sinusoidal motion. Also shown are the effects of varying the controlling parameters of the system including the stiffness constant, one, two, and three time delays, and methods of producing system stability including negative *RC* feedback and anticipatory control. A method is developed for setting up the analogy for a specific system on the transient analyzer by a suitable change in time and impedance bases.

WITH THE RAPID INCREASE in the use of accurate servomechanisms it has become desirable to provide a practical means of quickly and accurately analyzing in detail their performance under various operating conditions. The complexity of most servo systems makes it impractical to calculate transient response in any detail by conventional mathematical methods. Although it is usually possible to determine natural frequencies and damping rates, sufficient calculations to determine actual response for an optimum design is quite laborious and time consuming. The method of electrical analogy now has been applied to this type of system. Additional facilities in the form of special amplifier circuits have been developed to be used in conjunction with the mechanical-transients analyzer[1,2] for setting up the electrical analogue of many of the basic types of servo systems. With this equipment an analogous electric circuit is set up; the desired transient or steady-state condition to which the servo system must regulate is generated as an electrical excitation function; and the complete solution for its response is viewed or recorded on the screen of a cathode-ray oscilloscope. This paper treats the application of the transient analyzer to angular position servomechanisms, a fundamental analysis of which is given in reference 3.

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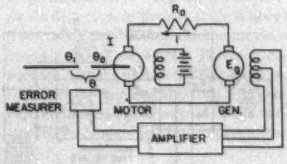
Electrical Analogies for Angular Position Servomechanisms

For most systems involving mechanical motion there are several practical electrical analogies.[3] Thus several completely electric circuits can be used to represent an electromechanical system. The one used here for angular position servomechanisms is illustrated in Figures 1 and 3. Figure 1 shows the case of a simple error-control system with no electric time delays. A single differential equation (equation 1) can be formed expressing the mechanical motion of the system in terms of both mechanical and electrical parameters. The inertia is represented by an inductance and the motor-generator armature circuit losses by a resistor. The analogue for the error measurer is the capacitor C_e of Figure 1. The voltage across it is proportional to the charge that is analogous to angular displacement $\theta_1 - \theta_0$ when the circuit for simulating the motion θ_1 to be followed by the servo system is connected as shown. A wide variation in the character of the motion θ_1 can be simulated with the excitation circuits of the mechanical-transients analyzer.[2] With these a voltage is produced proportional to the assumed velocity of the device to be followed. This feeds current into C_e through a relatively high resistor, so that the voltage across C_e is negligible during the period in which the solution is obtained. The capacitor voltage (which is the error voltage) also must be very small compared to the voltages across L and R of the servo analogy so as not to distort its motion. This requires a fairly large value of capacitance for C_e. The amplifier of Figure 1 completes the analogous circuit. Its output voltage E_g is analogous to the controller torque M_c, giving the simple relationship of equation 2 (Figure 1) for the stiffness constant K.

General solutions[3] of this simple system can be expressed readily in dimensionless form as shown in Figure 2. This is of considerable value, as it greatly increases the usefulness of the solutions. As will be shown later, solutions for the more com-



A—Mechanical system

Equation for armature circuit:

$$E_g = R_a i + g\frac{d\theta_0}{dt}$$

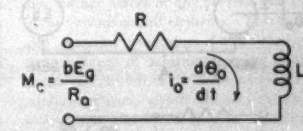
Equation for motor torque:

$$bi = I\frac{d^2\theta_0}{dt^2}$$

Combining in a single torque equation:

$$\frac{bE_g}{R_a} = I\frac{d^2\theta_0}{dt^2} + \frac{bg}{R_a}\frac{d\theta_0}{dt} = M_c = K(\theta_1 - \theta_0) \qquad (1)$$

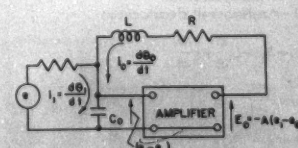
Figure 1. Electrical analogy used for simple error-control servomechanisms with no electric time delays



B—Analogous circuit for torque equation

$R = c = \frac{bg}{R_a}$

$L = I$



C—Complete analogous circuit

$M_c = K(\theta_1 - \theta_0) = A(e_1 - e_0)$

$(e_1 - e_0) = \frac{\theta_1 - \theta_0}{C_0}$

$$K = \frac{A}{C_0} \qquad (2)$$

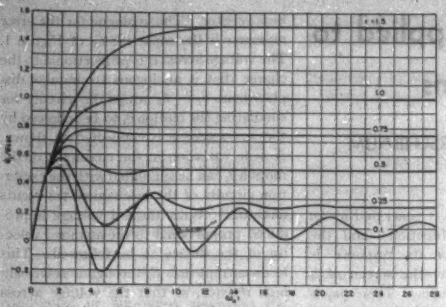
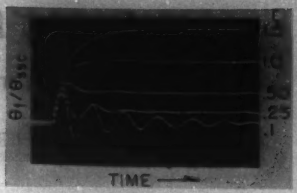


Figure 2 (left and right). Response curves of simple error servomechanisms to constant velocity



$\theta(t)$ = error angle as function of time

θ_{ssc} = steady-state error angle for critically damped systems

$$\theta_{ssc} = \Omega \frac{2r}{\omega_n}$$

ω_1 = magnitude of applied constant velocity

$$\omega_n = \sqrt{\frac{K}{I}} = \text{undamped natural frequency}$$

K = stiffness constant

I = total system inertia

$$r = \frac{c}{2\sqrt{IK}} = \text{ratio of actual to critical damping}$$

c = actual damping

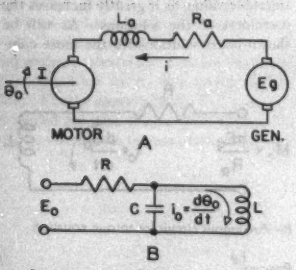
plex practical servomechanisms also can be put in this same dimensionless form. It is this characteristic that allows the use of a calculating board device (with a limited range of variation in its circuit constants) for the general solution of such problems. Thus for convenience in setting up a given system on the analyzer the time base and the impedance base can be changed arbitrarily to form a new system from which either the actual numerical solution for the given system or a dimensionless solution readily can be obtained. The conversion formulas for making these changes are given in Table I. These are understood readily from consideration of the equations at the bottom of the table. Since the ratios of the angular motion θ to the system torques are reduced by the factor a in the simulated system, its stiffness constant K' must be greater than the actual stiffness K by the same ratio. The application of this table to the solution of an actual problem will be illustrated later.

Effect of Additional Time Delays

The analogous circuit for cases where the motor generator armature circuit inductance is taken into account is developed in Figure 3a. This inductance has its analogy in a capacitance C_1, resulting in an RC time delay T_1. Other time delays, such as that in the generator field, can be represented by RC circuits placed between stages of the amplifier as shown in Figure 8b. It is necessary, however, that each delay circuit be isolated by a stage of amplification. Such time constants must be changed, when the time base is changed, as shown in Table I. When defining them for a general solution in dimensionless form they must be multiplied by ω_n.

Stabilization With RC Feedback

For servomechanisms of this type system stability frequently is obtained by



a. Representation of armature circuit inductance

A—Mechanical system
B—Analogous all-electric circuit

$$E_g = R_a i + L_a \frac{di}{dt} + g \frac{d\theta_0}{dt}$$

$$bi = I \frac{d^2\theta_0}{dt^2}$$

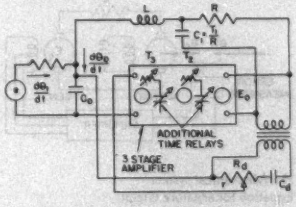
giving

$$M_c = \frac{bE_g}{Ra} = \frac{L_a I}{Ra} \frac{d^3\theta_0}{dt^3} + I \frac{d^2\theta_0}{dt^2} + \frac{bg}{Ra} \frac{d\theta_0}{dt}$$

Electric circuit equation:

$$E_0 = RCL \frac{d^3 i_0}{dt^3} + L \frac{di_0}{dt} + Ri_0$$

where, $R = \frac{bg}{Ra}$, $L = I$, $C = \frac{La}{bg} = \frac{T_1}{R}$



b. Analogous circuits for time delays and negative RC feedback

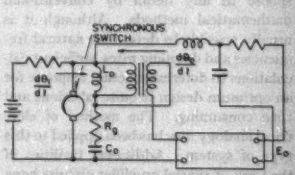
Equation for feedback voltage:

$$e_d = \frac{-rC_d p}{(1+pt_1)}(E_0 \equiv M_c)$$

$$p = \frac{d}{dt},\ t_1 = R_d C_d,\ n = \frac{r}{R_d}$$

$$e_d = \frac{-npt_1}{(1+pt_1)}(E_0 \equiv M_c)$$

Figure 3. Electrical analogies used for various elements of angular position servomechanisms



c. Analogous circuit for error-plus-error rates control

For actual system:

$$M_c = K(\theta_1 - \theta_0) + KT_{ap}(\theta_1 - \theta_0) + K(T_a)^2 p^2 (\theta_1 - \theta_0)$$

In analogous circuit:

$$E_0 \propto M_c$$

$$E_0 = \frac{A}{C_0}(\theta_1 - \theta_0) + AR_g p(\theta_1 - \theta_0) + AL_0 p^2(\theta_1 - \theta_0)$$

$$K = \frac{A}{C_0},\ T_a = \frac{AR_g}{K},\ (T_a)^2 = \frac{AL_0}{K}$$

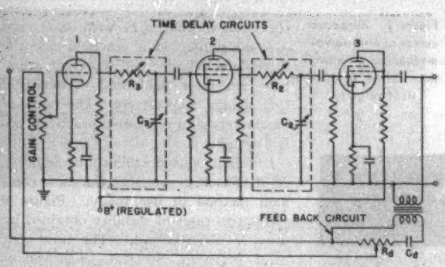


Figure 4. Circuit elements of amplifier used for servomechanism analogies

using a resistance-capacitor network connected across some voltage that is proportional to the controller torque M_c. The equation for the feed-back voltage from this type of circuit is shown in Figure 3b. It is put in general form by expressing it in terms of a dimensionless ratio n and a time constant t_1. For dimensionless solutions t_1 must be multiplied by ω_n.

Error-Plus-Error Rates Control

Other forms of system stability consist of providing an additional control torque term proportional to the first derivative of the error angle $\theta_1-\theta_0$ and possibly a negative term proportional to the second derivative of the error angle. The forms for these control functions together with their electrical analogy are given in Figure 3c. These functions are expressed in terms of the stiffness constant K and time constants, so that they can be defined readily in dimensionless form. In actual systems the control term proportional to the rate of change of the error angle (commonly called anticipatory control) usually must be produced by a mechanism having its own time delays. This is sometimes a gyroscopic mechanism. The method of representing these additional terms is shown in an example to be discussed later (see Figure 11).

Description of the Servomechanism Analyzer

Suitable amplifiers and associated circuits have been developed to be used in conjunction with the mechanical-transients analyzer to provide facilities for the rapid analysis of such servomechanisms as have been described above. The amplifier, typical elements of which are illustrated in Figure 4, is of the conventional resistance coupled type, designed to have a frequency response that is flat down to 10 cycles per second, that being the frequency at which the transient forcing functions usually are repeated on the analyzer.[1,2] This response is achieved by using large coupling and by-pass capacitors and by using a regulated power supply which prevents regeneration at low frequencies. Although the amplifiers must be linear, the added complication involved in using push-pull resistance coupled amplifiers was not justified, and single-ended triode amplifiers were found to be satisfactory. The maximum harmonic distortion in the last stage is about 5 per cent; the distortion in the previous stages is entirely negligible. Power amplifiers are used for all but the first stage, so that various damping and time delay circuits connected to the outputs of the various stages do not affect the amplification.

Time delay, such as that arising from the field of an exciter, is represented by a circuit such as R_3, C_3 of Figure 4. The voltage developed at the grid of the third tube will lag behind the plate voltage of the second tube in exactly the same way that an exciter armature voltage will lag behind the voltage applied to its field terminals. The time constant which describes this delay is R_3C_3 in seconds. Additional time delays can be introduced as shown at the input to the second stage. Resistance-capacitance feed-back damping voltages from the amplifier output are fed back to the input by using an isolating transformer. This transformer has very good frequency response down to 10 cycles per second, thus reproducing accurately the voltage which appears at the output of the amplifier. These transformers also may be used as damping transformers when simulating voltage regulating systems.[4] Flexibility in the general application of the amplifier is obtained by making the amplifier stages, the time delay circuits, the isolating transformers, and the RC feed-back circuit each a separate entity.

Figure 5 shows the laboratory equipment. To the right are the synchronous switches which repeat the transient 10 times per second. Next to the switches is the central control desk from which the operator can measure on the oscilloscopes any voltage across or any current flowing in the various circuit elements. This desk also contains generators for producing various types of arbitrary forcing functions. To the left is the servomechanism analyzer cabinet, which contains the amplifiers and associated circuits described in the accompanying paragraph. Low-loss inductances and capacitors for representing mechanical systems are contained in the cabinets arranged behind the control desk and servomechanism analyzer cabinet.

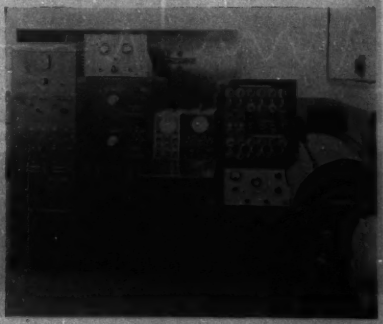


Figure 5. Setup in transients analyzer laboratory for the solution of servomechanism problems

Figure 6. Response curves of error servomechanism, with one time delay, to constant velocity

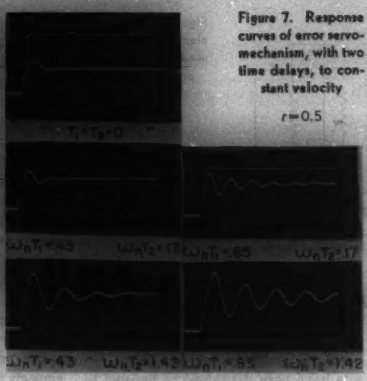


Figure 7. Response curves of error servomechanism, with two time delays, to constant velocity

$r=0.5$

Typical Solutions

In Figure 2 oscillograms are shown of general solutions for the response of the simple error control system to a constant velocity for comparison with calculated curves. The value of this method of analogy can be appreciated when it is considered that such a set of oscillograms can be obtained in a matter of minutes. Figures 6, 7, and 8 show the effect of time delays on the response of the typical angular position servomechanism to a suddenly applied constant velocity. Figure 6 shows the effect of varying the magnitude of a single time delay. The magnitudes of the time delays are given in the dimensionless form, $\omega_n T$, so that the results have general application. The results with $\omega_n T_1$ constant and a second time delay, $\omega_n T_3$, varied are given in Figure 7. Similarly, Figure 8 shows the effect of varying $\omega_n T_3$ with $\omega_n T_1$ and $\omega_n T_2$ constant. In a practical case the three time delays could represent armature, generator field, and exciter field time delays, respectively. The range of parameters used represents practical control systems.

Obtaining system stability by negative RC feedback is probably the most common method in use today. Figure 9 shows two cases of stability obtained by negative RC feedback. The time constant of the RC circuit, $\omega_n t_1$, as well as the system damping and time delays, all are given in dimensionless form. The large initial overshoot and the considerable reduction in system frequency which is always characteristic of negative RC feedback is quite apparent in each of the two examples shown in Figure 9. The RC time constants are large, when compared with the system time delays, and are in the optimum range for best results.

The response of any servomechanism to a sinusoidal forcing function is usually of great interest in design. Figure 10 shows the response of an angular position servomechanism to a suddenly applied sinusoidal motion of varying frequency, ω_i.

Figure 8. Response curves of error servomechanism with three time delays, to constant velocity

$r=0.5$

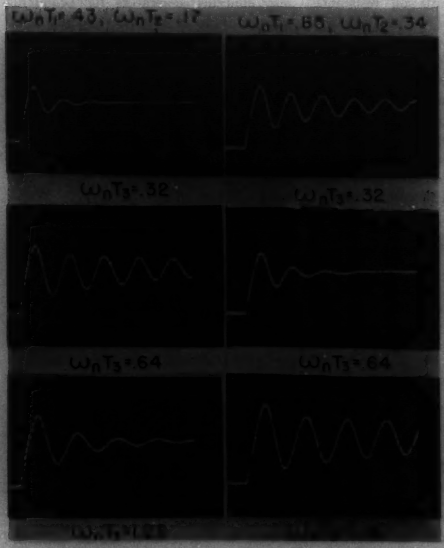
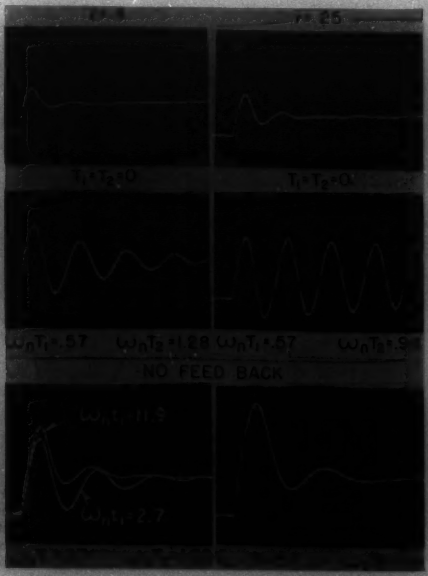


Figure 9. Response curves of error plus negative RC feedback servomechanism with two time delays to constant velocity



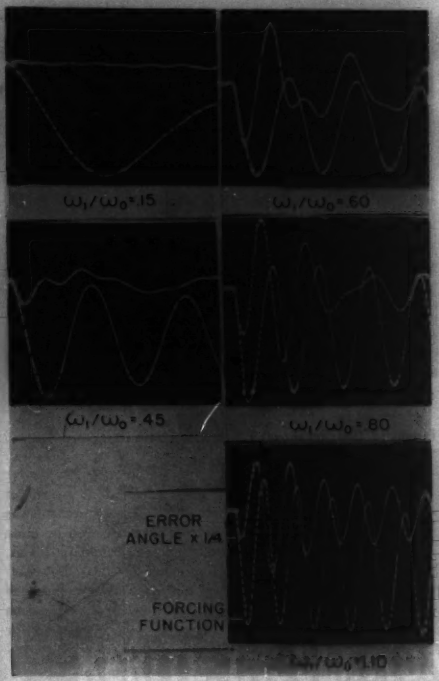


Figure 10. Response curves of error servomechanism to sinusoidal motion

$r = 0.17$

The response at frequencies well below the system frequency, ω_0 is quite good with hardly any error appearing. However, as the frequency is increased, the response becomes poorer with large following errors. When ω_1 is very close to ω_0, such as the case $\omega_1/\omega_0 = 1.10$, the error actually becomes larger than the applied disturbance θ_1. The steady-state response to sinusoidal motion also can be obtained quite easily when an oscillator is used as the excitation function for θ_1.

Tank Turret Traverse Servo System

The following example serves to further illustrate the application of the electrical analogies and the conversion formula of Table I to the solution of a specific system. This problem is that of an electric drive that had been designed for the traverse movement of a tank turret.[5] The schematic of the mechanical system, its equation of motion, the analogous electric circuit, and the units for both the actual system and the electrical analogy are given in Figure 11a. The gyroscope in the actual system serves as the means for obtaining system stability. If the gyroscope is rotated proportional to $\theta = (\theta_1 - \theta_0)$ and is also capable of restrained rotation about an axis 90 degrees from the θ axis; any point of the gyroscope not on either axis has a motion proportional to $\theta + p\theta$. This motion is used to operate a silverstat in the generator field circuit. This is anticipating control and is a phase advance that tends to compensate for the system time delays. The rate component of gyroscope movement is caused by the gyroscope torque, exerted about the 90-degree axis, that is proportional to the speed of rotation about the θ axis. There is spring restraint, inertia, and critical damping about the 90-degree axis, so that instead of a rotation instantaneously proportional to $p\theta$ (as shown in Figure 3b) it is delayed and appears as the term

$$\frac{KT_a p(\theta_1 - \theta_0)}{(1 + t_1 p)^2}$$

of the mechanical system equation shown in Figure 11a. T_a is the ratio of torque per unit velocity error, $p\theta$, to torque per unit displacement error, θ.

With the constants shown in Figure 11a, the calculated turret frequency was 1.4 cycles per second and the damping decay 78.1 per cent per cycle.[5] The oscilloscope record of Figure 11b with delayed anticipation represents the same calculation and checks to within 5 per cent or better. The remaining oscillographs of Figure 11b show the system as it would hunt without any means of obtaining system stability; what could be done with negative *RC* feedback, with undelayed anticipation, and what could be done by a combination of negative *RC* feedback and delayed anticipation. The two disadvantages of negative *RC* feedback compared with anticipating control are quite apparent in Figure 11b. The initial overshoot is much greater, and the system frequency has been considerably reduced. The combination of anticipation and some *RC* feedback gives the best response for this particular example. It is to be noted, however, that the improvement over anticipation alone is not too

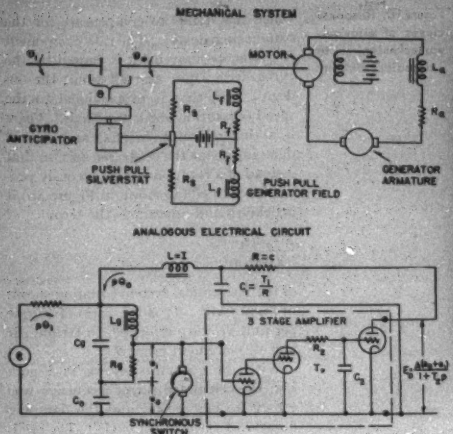
Table I. Conversion Formula for Changing Time and Impedance Bases in Setting Up Analogy for Servomechanisms

Actual System	Time Base Changed to $t' = t/n$	Impedances Multiplied by Constant a
L (henrys) $= I$ (pounds-inch-seconds^2)	$L' = L/n^2$	$L'' = aL/n$
R (ohms) $= c = \frac{bI}{R_a}$ (inch-pounds/radians per second)	$R' = R/n$	$R'' = aR/n$
E_a (volts) M_c (inch-pounds)	$E_a' = E_a$	$E_a'' = E_a$
i_1, i_2 (amperes) $\alpha \frac{d}{dt}(\theta_1, \theta_0)$ radians per second	$\theta' = \theta$	$\theta'' = \theta/a$
$\omega_n = 2\pi \times$ undamped natural frequency	$\omega_n' = n\omega_n$	$\omega_n'' = n\omega_n$
$K = \omega_n^2 I$	$K' = K$	$K'' = aK'$
$K = M_c/(\theta_1 - \theta_0)$	in analogous electric circuit	$K'' = A/C_3$
Time delays T (seconds)	$T' = T/n$	$T'' = T/n$

Equation for simple error servomechanism: $M_c = K(\theta_1 - \theta_0) = \frac{bEg}{R_a} = L\frac{d^2\theta_0}{dt^2} + R\frac{d\theta_0}{dt}$

Transformation to time base $t' = t/n$: $Mc' = L/n^2 \frac{d^2\theta_0'}{dt'^2} + \frac{R}{n}\frac{d\theta_0'}{dt'}$

Multiplying impedances by a: $M_c'' = \frac{aL}{n^2}\frac{d^2\theta_0''}{dt''^2} + \frac{aR}{n}\frac{d\theta_0''}{dt''}$



11a. Analogous circuit and system constants

Equation for mechanical system:

$$I p^2\theta_0 + \frac{c p \theta_0}{1+T_1 p} = \frac{K\left(1+\frac{T_2 p}{(1+t_1 p)^2}\right)\theta}{(1+T_3 p)(1+T_4 p)}$$

Units

Actual mechanical system:

$I = 7.78\times10^{-3}$ pound-inch seconds^2
$c = 0.33$ inch-pound per radian per second
$T_1 = 0.02$ second
$T_3 = 0.1$ second
$K = 4$ inch-pounds per radian
$T_4 = 0.15$ second
$t_1 = 0.01$ second

Converted electric system with $n = 200$ and $a = 3.1\times10^4$

$$L'' = \frac{aI}{n^2} = 6.02 \text{ henrys}$$

$$R'' = \frac{ac}{n} = 5{,}130 \text{ ohms}$$

$$T_1'' = \frac{T_1}{n} = 10^{-4} \text{ seconds}$$

$$T_3'' = \frac{T_3}{n} = 5\times10^{-4} \text{ seconds}$$

$K'' = aK = 12.2\times10^4$
$C_3'' = 14\times10^{-6}$ farads
$A'' = K''C_3 = 171$

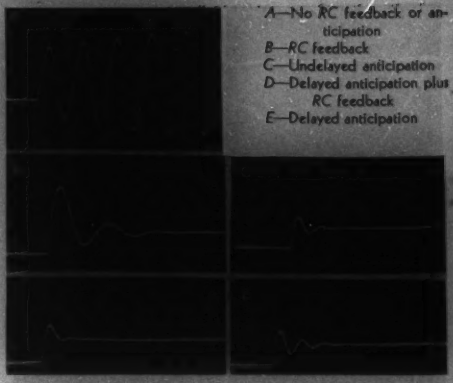
$$T_4'' = T_4/n = 7.5\times10^{-4}$$

$$R_1'' = \frac{K''T_4''}{A''} = 54 \text{ ohms}$$

$$t_1'' = t_1/n = 5\times10^{-5} \text{ seconds}$$

$$C_1'' = \frac{2t_1''}{R} = 1.86\times10^{-6} \text{ farads}$$

$$L_1'' = \frac{R_1''t_1''}{2} = 1.35\times10^{-3} \text{ henrys}$$



11b. Response curves to constant velocity

Figure 11 (left and above). Tank turret traverse servomechanism

great and would not warrant the use of much extra equipment.

Conclusions

From the examples shown it can be seen that the transients analyzer offers an excellent method for solving fundamental servomechanism problems. The ease with which the response of systems involving high order differential equations can be obtained points the way toward many useful solutions not only of particular systems but also in dimensionless form for general application. The accuracy of the method has been demonstrated by close checks with previously calculated cases. It therefore provides a reliable and practical method for the general analysis of certain basic types of servomechanisms and of specific systems too complex for adequate study by conventional mathematics.

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5. Electric Turret Traversing Mechanism for the M-6 Tank, S. J. Mikina, Jr. *Applied Mechanics*, December 1945, page 334.

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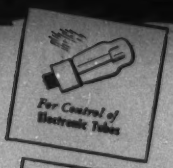

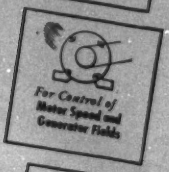

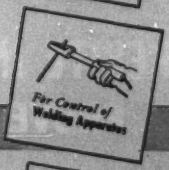

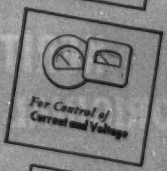

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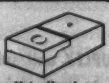
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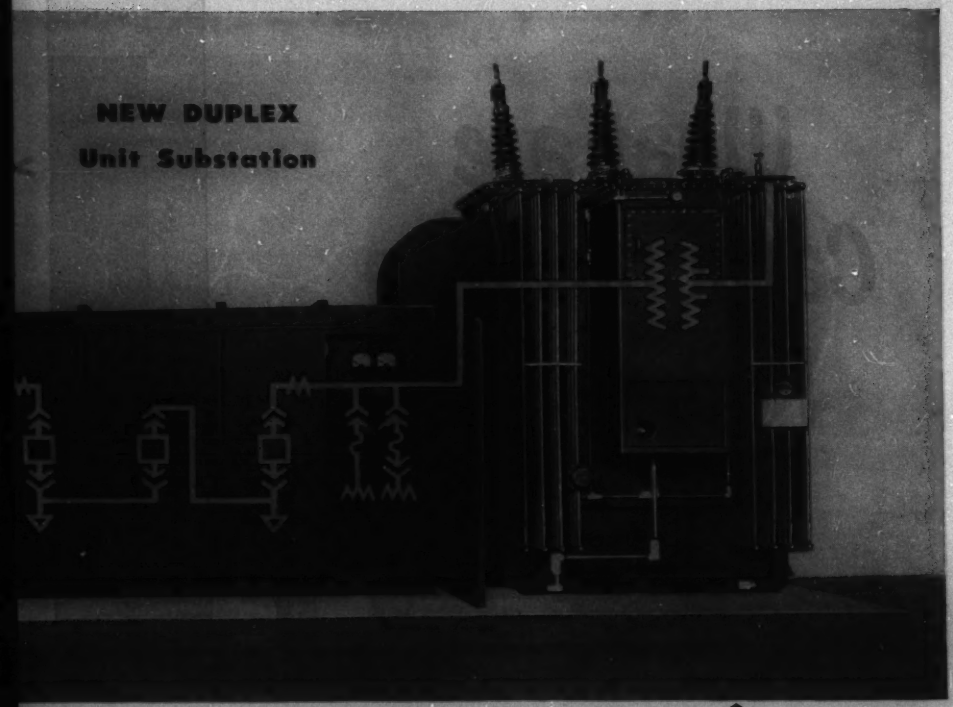

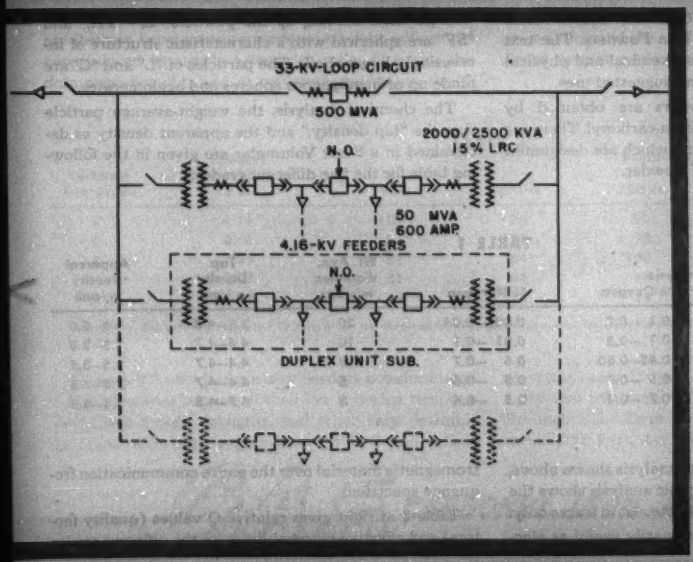

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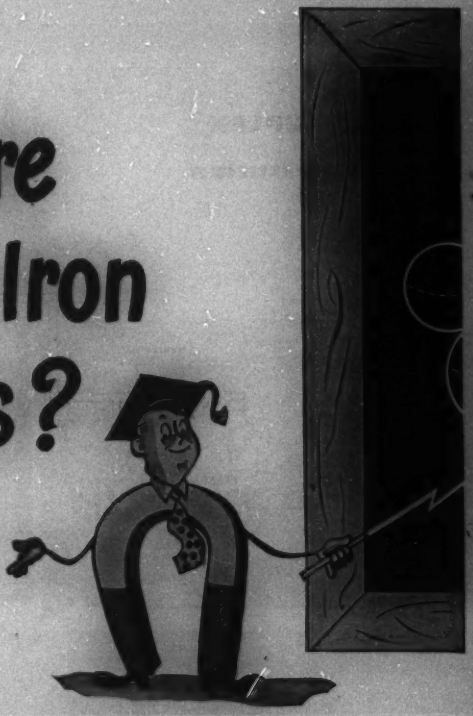


ABOVE you see the fundamental characteristics found only in G.A.F. Carbonyl Iron Powders. The text below outlines kinds of powders, chemical and physical analysis, including "Q" value, and suggested uses.

G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as "L," "C," "E," "TH," and "SF" Powder.

The particles making up the powders "E," "TH," and "SF" are spherical with a characteristic structure of increasingly larger shells. The particles of "L" and "C" are made up of homogenous spheres and agglomerates.

The chemical analysis, the weight-average particle size, the "tap density," and the apparent density as determined in a Scott Volumeter are given in the following table for the five different grades:

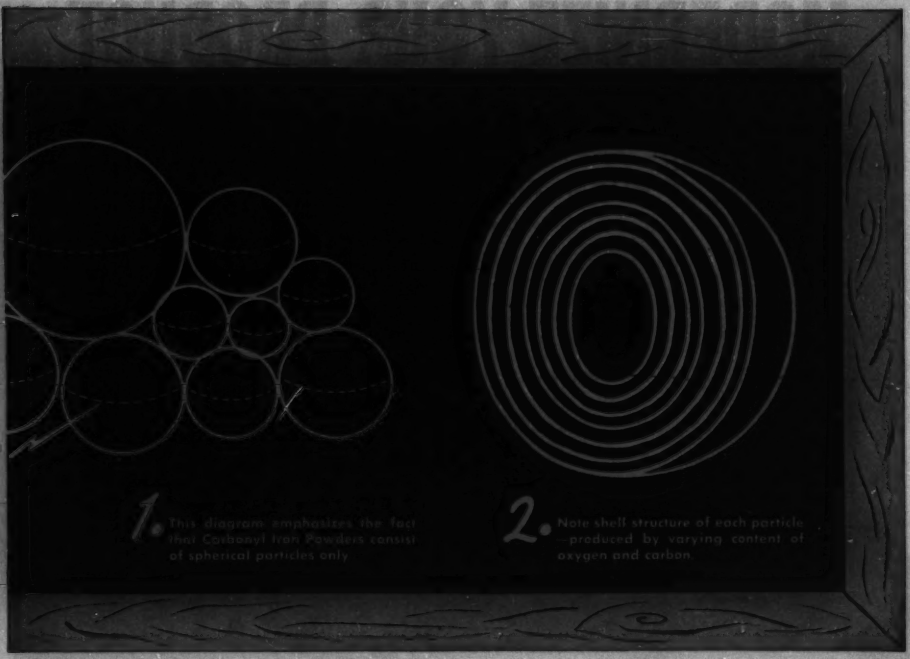
TABLE 1

Grade	Chemical Analysis % Carbon	% Oxygen	% Nitrogen	Wt. Ave. diameter microns	Tap Density g/cm3	Apparent Density g/cm3
L	0.005—0.03	0.1 —0.2	0.005—0.05	20	3.5—4.0	1.8—3.0
C	0.03 —0.12	0.1 —0.3	0.01 —0.1	10	4.4—4.7	2.5—3.0
E	0.65 —0.80	0.45—0.60	0.6 —0.7	8	4.4—4.7	2.5—3.5
TH	0.5 —0.6	0.5 —0.7	0.5 —0.6	5	4.4—4.7	2.5—3.5
SF	0.5 —0.6	0.7 —0.8	0.5 —0.6	3	4.7—4.8	2.5—3.5

With reference to the chemical analysis shown above, it should be noted that spectroscopic analysis shows the rest to be iron with other elements present in traces only.

Carbonyl Iron Powders are primarily useful as electromagnetic material over the entire communication frequency spectrum.

Table 2 at right gives relative Q values (quality factors) and effective permeabilities for the different grades


1. This diagram emphasizes the fact that Carbonyl Iron Powders consist of spherical particles only.
2. Note shell structure of each particle produced by varying content of oxygen and carbon.

of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

TABLE 2

Carbonyl Iron Grade	Effective Permeability at 1 kc	Relative Quality Factor at 10 kc	150 kc	200 kc	1 Mc	100 Mc
L	4.16	100	96	90	43	1
C	3.65	94	100	98	72	3
E	3.09	81	94	100	97	30
TH	2.97	81	93	98	100	54
SF	2.17	62	71	78	84	100

(Note: The actually measured Q values can be obtained by multiplying the rows respectively with: 0.78, 1.09, 1.25, 2.63, and 1.62.)

"L" and "C" powders are also used as powder metallurgical material because of their low sintering temperatures, high tensile strengths, and other very desirable qualities. (Sintering begins below 500°C and tensile strengths reach 150,000 psi.)

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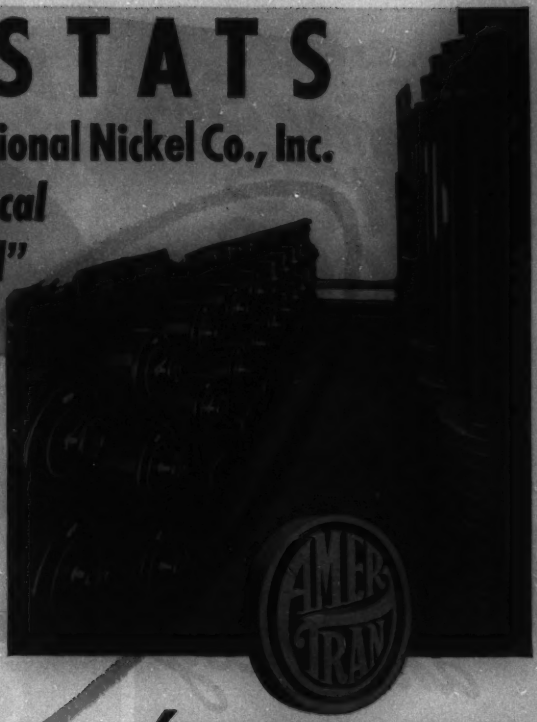

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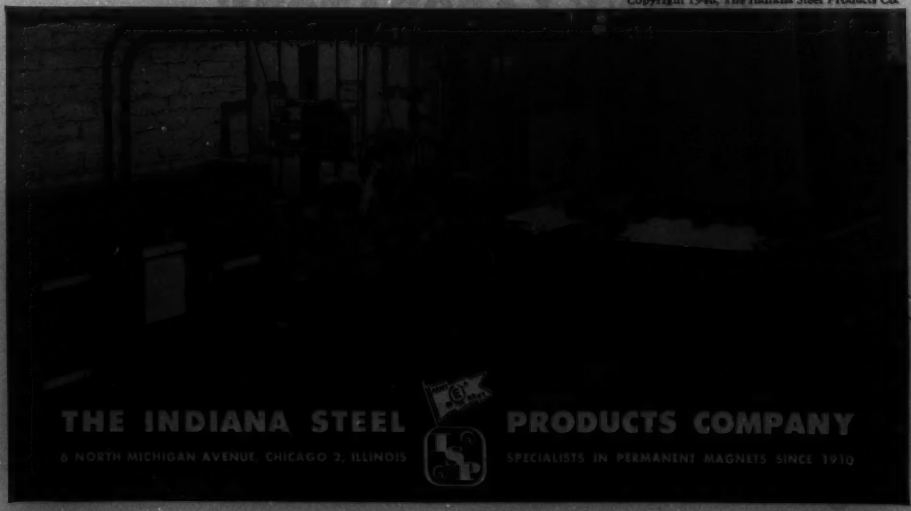
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SPECIALISTS IN PERMANENT MAGNETS SINCE 1910

Important Features

- Simple in Design
- Easy to Install
- All Pieces Preformed
- Inexpensive
- Reinforces Conductor
- Increases Conductor Life
- Prevents Conductor from Chafing on Insulator
- No Complicated Tools Needed
- Holds Strongly Against Unbalanced Line Tension
- Meets Requirements of National Electrical Safety Code
- Assures Uniformly Good Results

NEW COMPLETELY PREFORMED INSULATOR TIE

Copperweld GRIP-FLEX 45

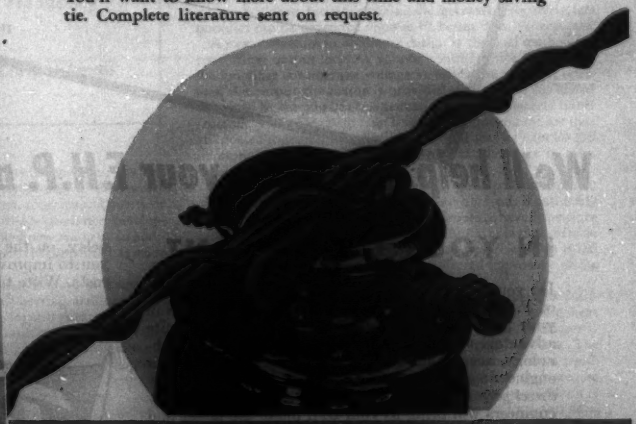
for use with Copperweld and Copperweld-Copper Conductors

Every lineman's reaction when he sees for the first time the Copperweld GRIP-FLEX 45 Insulator Tie is—"It's so simple. Why didn't I think of it?"

Yes—simplicity is one of the outstanding features of this distinct improvement over all hand wrapped ties. But it required years of engineering and testing before we could give you a tie so simple that every lineman can make a good tie the first time he applies it.

Careful prefabrication is the reason—all parts are precisely formed by machine to fit exactly and to give uniform results in tying.

You'll want to know more about this time and money saving tie. Complete literature sent on request.



Manufactured By
COPPERWELD STEEL COMPANY
GLASSPORT, PA.

Sold by
ANACONDA WIRE & CABLE COMPANY, NEW YORK, N. Y.
COPPERWELD STEEL COMPANY, GLASSPORT, PA.
KENNECOTT WIRE & CABLE COMPANY, PHILLIPSDALE (RUMFORD), R. I.
PHELPS DODGE COPPER PRODUCTS CORPORATION, NEW YORK, N. Y.

to serve you better, faster
F. A. SMITH MANUFACTURING CO., INC.
ANNOUNCES
DIRECT FACTORY REPRESENTATION
BY TRAINED F.H.P. MOTOR ENGINEERS
BEGINNING JANUARY 1, 1946

We'll help you solve your F.H.P. motor problems

IN YOUR OWN PLANT

Do you use or plan to use production-run quantities of F.H.P. motors (1/500 to 1/15 H.P.) or blowers in your products? Then our new policy means definite advantages to you. Now, our extensive motor technology, accumulated through years of F.H.P. motor engineering and manufacture, is available to you by *direct personal contact*. Our skilled, experienced factory engineers will bring to your own plant the latest and most complete technical information. Design, engineering and production problems can be solved without delay, on the spot. This new service may help you to improve product performance and lower costs. Write today, outlining your problem.

Pilot
Fractional H.P.
MOTORS
& BLOWERS

F. A. SMITH MANUFACTURING CO., INC.
450 DAVIS STREET ROCHESTER 2, N. Y.

FASCO

hp LABORATORY INSTRUMENTS FOR SPEED AND ACCURACY

A New -hp- AF Oscillator

MODEL 201B

OUTSTANDING NEW FEATURES

3 Watts Output

Distortion Less Than ½ of 1%

Low Hum Level

New Dial With Ball-Bearing Drive

Accurate Expanded Frequency Calibration

Improved Control of Output Level

In FM and other fields where high fidelity is important, this new -*hp*- Model 201B Audio Frequency Oscillator will meet every requirement for speed, ease of operation, accuracy and purity of wave form. The product of 6 years of -*hp*- oscillator development, this new oscillator has many brand new features, in addition to the revolutionary resistance-tuned circuit which has made -*hp*- a byword in engineering circles.

The 201B has an accurate, convenient method of frequency control. The 6" dial, with smooth ball-bearing action, may be tuned by a directly controlled knob, or for still greater accuracy, may be set by the vernier which has a ratio of 6 to 1 to the main dial. The illuminated main dial is designed so that parallax is eliminated. It is calibrated over 300 degrees with approximately 95 calibration points and has an effective scale length of about 47 inches. The frequency range is 20 cps to 20 kc.

The amplifier delivers up to 3 watts of power into a 600 ohm resistance load, with distortion held to less than ½%. Thus there is sufficient power available for driving almost any kind of laboratory or production equipment. Harmonic distortion may be kept to less than ½ of 1%, if the output of the amplifier is limited to 1 watt.

Another important feature of this oscillator is the provision which is made for standardizing each frequency range against a reliable standard, such as -*hp*'s- Model 100B Secondary Frequency Standard. By standardizing the instrument regularly, frequencies can be depended upon to be better than 1% accurate.

A new departure in oscillator design is the dual method for controlling output level. A volume control which is ahead of the amplifier controls the voltage at which the amplifier operates. An output attenuator is provided to attenuate the signal delivered by the amplifier. Attenuation is approximately linear from zero to 40 DB. Both hum level and output voltage are thus attenuated together. As a result, hum level may be kept 60 DB or more below the signal level, a special advantage in cases where small test signals are used.

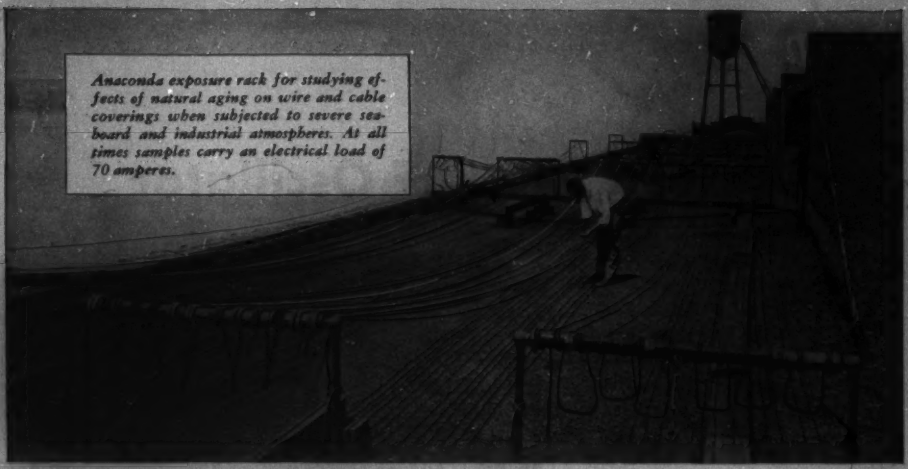
The impedance looking back into the out circuit is about 50 ohms; thus the voltage regulation for varying loads is extremely good. For measurements where it is desirable to have impedance looking back into the instrument of 600 ohms, as in transmission measurements, the attenuator may be used to give about 6 DB or more of attenuation, making the reflected impedance of the instrument about 600 ohms.

Care has been taken to perfect every detail of this new oscillator. Improved chassis layout and placement of component parts minimizes thermal drift. The voltage on the oscillator is maintained constant with an electronic voltage regulator. The entire instrument is characterized by greater mechanical rigidity; the tuning assembly is mounted on a sturdy cast aluminum frame. The chassis itself is made of aluminum; the oscillator is light in weight and easy to handle. Write today for latest data, prices and delivery information on this versatile, accurate resistance-tuned oscillator.

HEWLETT-PACKARD COMPANY

BOX 1158A • STATION B • PALO ALTO, CALIFORNIA

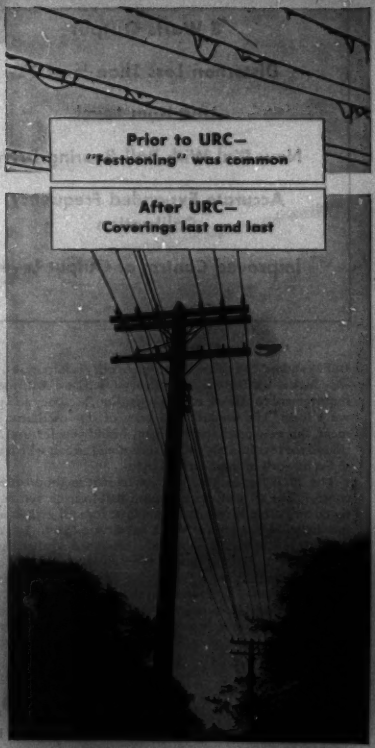
Audio Frequency Oscillators *Signal Generators* *Vacuum Tube Voltmeters*
Noise and Distortion Analyzers *Wave Analyzers* *Frequency Meters*
Square Wave Generators *Frequency Standards* *Attenuators* *Electronic Tachometers*



Anaconda exposure rack for studying effects of natural aging on wire and cable coverings when subjected to severe seaboard and industrial atmospheres. At all times samples carry an electrical load of 70 amperes.

Rigid tests prove URC Weatherproof lasts and lasts...

Besides the severe tests applied to the components of Anaconda Weatherproof, the finished wire and cable is subjected to long natural aging tests as shown in the accompanying pictures. These exposures are supplemented by laboratory accelerated aging tests. Both types indicate a trouble-free service capacity for years and years.



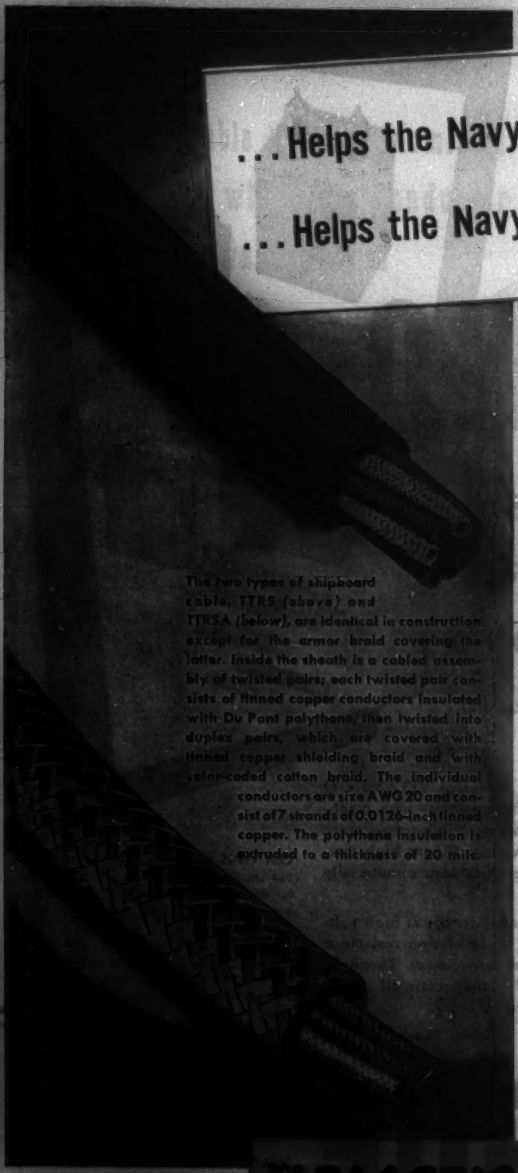
ANACONDA

For Continuity of Service . . .
Anaconda Triple Braid or
Duraline URC

LOOK TO *Anaconda* FOR WEATHERPROOF THAT LASTS!

. . . Helps the Navy to **SEE** the target
(IN RADAR)

. . . Helps the Navy to **HIT** the target
(IN FIRE CONTROL)



The two types of shipboard cable, TTRS (above) and TTRSA (below), are identical in construction except for the armor braid covering the latter. Inside the sheath is a cabled assembly of twisted pairs; each twisted pair consists of tinned copper conductors insulated with Du Pont polythene, then twisted into duplex pairs, which are covered with tinned copper shielding braid and with color-coded cotton braid. The individual conductors are size AWG 20 and consist of 7 strands of 0.0126-inch tinned copper. The polythene insulation is extruded to a thickness of 20 mils.

Shipboard cable insulated with Du Pont POLYTHENE

The shipboard cables here illustrated furnish another striking example in the growing list of difficult insulation jobs done capably by Du Pont's versatile plastic, polythene. These cables, manufactured by Rockbestos Products Corporation of New Haven, Conn., are used by the Navy for three functions: for transmission of synchronizing voltages in fire control equipment, for indicator sweep voltages, and for video frequency receiver output signals. In use they transmit signals from circuit to circuit as in a telephone circuit.

Polythene offers outstanding advantages as an electrical insulation. Because of its high dielectric strength, only a minimum thickness is needed. Polythene's low power factor makes it exceptionally effective for high-frequency wire, such as is used extensively in television. Polythene is chemically inert, light in weight (specific gravity 0.92) and retains its toughness and flexibility at temperatures ranging from —50° F. to 200° F.

For complete data sheet on polythene, write E. I. du Pont de Nemours & Co. (Inc.), Plastics Dept., Arlington, N. J.

DU PONT

FOR PLASTICS.. CONSULT DU PONT

BETTER THINGS FOR BETTER LIVING
. . . THROUGH CHEMISTRY

Specify *VITAMIN Q for

HIGHER VOLTAGES
(Real space savers)

HIGHER TEMPERATURES
(De-rating factor much smaller)

HIGHER INSULATION RESISTANCE
(More than 20,000 meg. mfds. at room temperature)

SPRAGUE CAPACITORS using the exclusive VITAMIN Q impregnant make possible the use of much smaller units—with a substantial safety margin—on numerous high-voltage, high-temperature applications ranging from transmitting to television. Where high temperature is not a factor, their unique characteristics assure materially higher capacity-voltage ratings for a given size.

Type 25P VITAMIN Q Capacitors operate satisfactorily at high voltages at ambient temperatures as high as 115° C. Insulation resistance at room temperature is *more than 20,000 megohm microfarads.* Throughout the temperature range of +115° C. to —40° C. they retain all virtues of conventional mineral oil-impregnated capacitors.

Sprague Electric Company, North Adams, Mass.

CAN TYPES 25P
Two standard types, one for 105° C. and one for 95° C. continuous operation. Other ratings available.

HERMETICALLY SEALED IN GLASS TUBES
Famous Sprague glass-to-metal end seals. Extended construction gives maximum flashover distance between terminals.

ARMY E NAVY

SPRAGUE

WRITE FOR CATALOG 20A . . .
including all Sprague Paper Dielectric Capacitor types.

CAPACITORS • *KOOLOHM RESISTORS • *CEROC INSULATION

*Trademarks Registered U. S. Pat. Off.

Alcoa Cable was All-Aluminum in 1905 when this conductor was installed

Alcoa introduced A-C-S-R *in 1909*

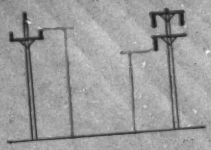
Still in service after forty years, this Alcoa Aluminum cable had its picture taken to illustrate this fact: Alcoa's recommendations on line construction and Alcoa A.C.S.R. are backed by many years' experience.

That's why it pays to come to Alcoa when you are planning a line. That's why you profit when you build with Alcoa A.C.S.R. Hi-line or rural line, your construction is more economical, most dependable, when you employ these conductors according to standards recommended by Alcoa engineers.

For help in designing or erecting a power line, get in touch with the nearby Alcoa district office. Or write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Bldg., Pittsburgh 19, Pa.

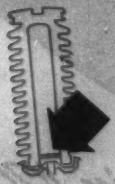
ALCOA A-C-S-R

LINE POST CONSTRUCTION IS ECONOMICAL FOR CONVERSION TO HIGHER VOLTAGES *OR* NEW BUILDING

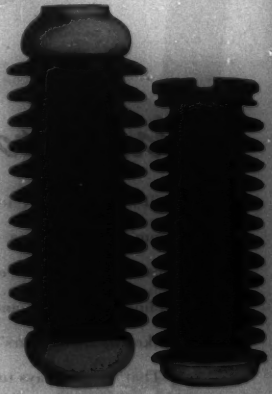


Any still-sound transmission line can be converted to higher voltage at low expense—and economically of manpower—by reinsulation on Line Posts. Ordinarily only new cross-arms and insulators are needed, and the job can be done with hot-line tools or during low-demand hours. For new construction, Line Posts offer substantial advantages in cost and operating performances. Because of the Line Post's upright height, it provides extra ground clearance —or in some cases the opportunity to use poles of the next shorter length.

LAPP LINE POSTS ARE LONG-LIVED... ALL HARDWARE EXTERNALLY ATTACHED



A feature of the Line Post in the original Lapp design was the *external attachment of all hardware,* and the elimination of nested porcelain parts. An inherent characteristic of porcelain is that it is at least ten times as strong in compression as in tension. Much of the failure from cracking in conventional insulators comes from bursting tension forces induced by thermal change. Lapp considers that its original conception was sound, and offers Line Post and Station Post insulators with all hardware externally attached—and still claims *"no cracking"* as a feature of these units.



Lapp

LAPP INSULATOR COMPANY, INC., LE ROY, N. Y.

Telephone TP-6. This unit has carrier amplifiers which triple the range of field wires.

Telephone Repeater TP-14 has unusual flexibility in providing economical performance on all types of lines.

Federal's versatile EE-89 Telephone Repeater ...the first standardized by our combat forces.

The FTR 165-B Voice Frequency Ringer furnishes an ideal unit for low frequency ringing current.

Federal's Telegraph Terminal TS-1/FCC-1 permits two-way telegraph communication over telephone circuits, without loss of voice communication.

This compact portable FTR 166 Repeater proved the answer to exacting demands in the USSR.

Federal's Exclusive Telephone Developments

...BATTLE TESTED...

Introduce New Concepts of Efficiency In Peacetime Transmission Equipment

Long recognized as a leader in designing and manufacturing the most advanced telephone and telegraph transmission equipment . . . Federal is now incorporating in commercial units the vast specialized experience and technique gained through wartime achievements such as exemplified by the exclusive Federal developments shown above.

Built to multiply channels and ranges of wire lines in war . . . the new Federal developments mark the advent of higher levels of performance and dependability . . . in modern compact units now available for commercial use.

These new advancements . . . of far-reaching effect on communications planning . . . emphasize the value of consultation with Federal's engineers. Call on Federal first for the finest in transmission equipment.

Federal Telephone and Radio Corporation

An IT&T Associate

Newark 1, N. J.

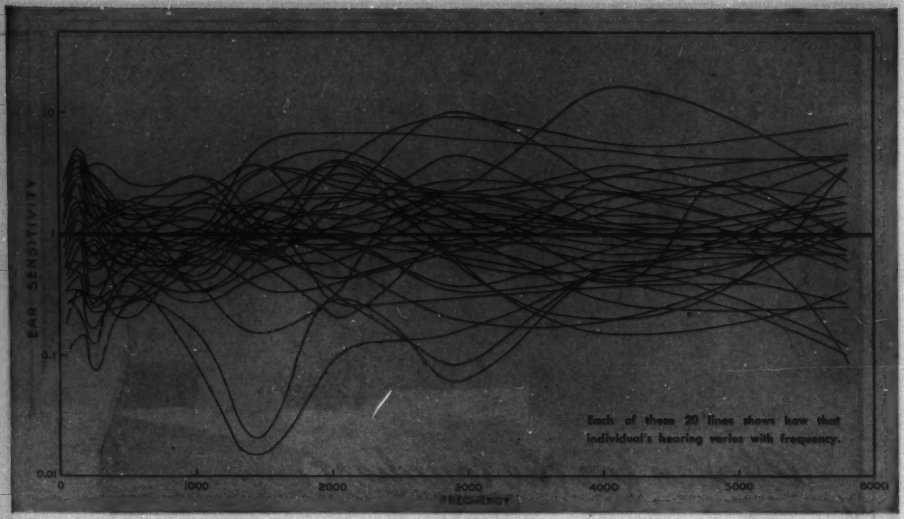
IT PAYS TO BUY EQUIPMENT THAT PAYS FOR ITSELF

RAISE POWER-FACTOR QUICKLY, ECONOMICALLY—LOWER OPERATING AND POWER COSTS

With low power-factor you are paying out dollars and cents for which there is no return. With C-D Capacitors, power-factor can be improved quickly, line voltage drop is reduced, motors will develop rated starting and running torque, and, feeder capacity will be released for additional equipment.

Cornell-Dubilier Capacitors are easily obtained and installed. They can be positioned where needed—readily moved to other locations. Average costs, installed, are from $6.15 per kva to $13.00. Saving on down-time, improved efficiency, combined with economies in demand charges soon pay for the capacitor installation. C-D power-factor improvement capacitors are a sound investment—not an expense. Ask your local C-D engineer for a quick estimate of the increase in capacity and saving possible in your plant, or write Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey.

Cornell-Dubilier [illegible] Capacitors



To measure is to know

Twenty-five years ago, one standard of sound power was the ticking of a watch, another was the clicking of two coins; and the measure was how far away the tick or the click could be heard. That test was made in measuring people's hearing, a field of interest to the Bell System scientists because the ear is the end-point of every talking circuit.

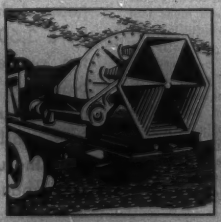
Accustomed to exact measurements, Bell scientists proceeded to develop a method of measuring hearing-sensitivity in terms which could be precisely defined and reproduced. After plotting hundreds of runs like those above, they decided on a particular sound intensity, representing an average "threshold of hearing," as a starting point.

The sounds delivered by a telephone line had previously been evaluated by listeners who compared their loudness with that of a standard source. There were wide variations in ears, as the chart shows, so the engineers replaced them by electrical instruments. When later their associates developed the Western Electric radio and public address systems, the necessary measuring circuits were promptly forthcoming. Addition of a standard microphone made a noise meter, widely used in quieting airplanes and automobiles.

"Through measurement to knowledge," said a famous Netherlands scientist. The principle finds wide application in Bell Laboratories, whether the quest be for a way to measure sound, a new kind of insulation, or more economical telephone service.

Hearing was first measured reliably by engineers in the Bell Telephone Laboratories

For good reception, program loudness must stay within certain limits. Volume-meters help to hold it there



From the throat of this mighty air-raid siren comes the loudest sustained sound ever produced

Visible Speech, result of telephone research, turns sound into "pictures" that the deaf can read

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for continued improvements and economies in telephone service

And THEY CAN TAKE IT!

NATIONAL ELECTRIC COILS SERVE ON ICE-BREAKER

When a 3700-ton motor-driven car ferry is used as an ice-breaker in the northern reaches of the Great Lakes, the coils of its motors *must* be good. It's murderous service —full speed ahead, grind to a stall, full speed reverse, then full speed ahead again. Such service makes maximum demands on coils. Complete dependability is essential; the water is rough; frequent starting, stopping and maneuvering are involved; the ship is steered by the speeds of its two propellers; precise spotting is required. The ferry shown above, breaking the ice for other less stout-hearted ships, is driven by twin screws, each powered by a 3,600 HP motor with rotor mounted directly on the propeller-shaft. Each motor is equipped with National replacement coils. That simple fact is a tremendous coil recommendation to you that you call your nearby National field representative to help you whip the unusual coil problem and to get the most in performance out of the ordinary coil installation.

IMPROVEMENT —NOT MERELY REPLACEMENT

To have replaced the previous coils in these two motors without discovering and correcting the causes of trouble would have invited a repetition of the failure. National engineers found that lamination supports were flexing and that the dovetail keys had loosened. Gussets were added to strengthen lamination supports. Simple, easily-operated key tightening devices were designed and built in. Laminations were re-stacked. All this in 22 days—including coil manufacture in our plant and installation in the field. The result? Performance improved, life lengthened. That's profit for the operator.

NATIONAL ELECTRIC COIL COMPANY

COLUMBUS 16, OHIO, U. S. A.

VACUUM CLEANERS · WASHING MACHINES · ELECTRIC FANS
SEWING MACHINES · ELECTRIC DRILLS · ELECTRIC RAZORS
FOOD AND DRINK MIXERS · REFRIGERATORS · POWER SANDERS
PHONOGRAPHS · ELECTRIC SAWS · CIRCULATING MACHINES

An Invitation

to makers of fractional-horsepower motor appliances!

MANY manufacturers have solved their fractional-horsepower motor brush problems for their new appliances simply by putting it up to National Carbon Company's brush-testing laboratory.

We invite you to do the same! This will relieve you of making countless and costly "elimination tests." And it will assure application of the most suitable brush grade for your motor.

You can rely on this service because National Carbon has been working out brush problems of every conceivable type for over 50 years. In addition, National Carbon's modern laboratory for testing fractional-horsepower motor brushes is equipped with the latest in test facilities, and is staffed by experts.

Moreover, your tests will be run as you would run them yourself — under your own specified load, cycle, and other operating conditions.

Accept this invitation! It can mean better performance for your appliances. Send in your motors —tests will be made promptly. Naturally, there is no obligation.

If you wish more information on these tests, get in touch with our nearest Division Office.

Here is the modern laboratory where your brush problem can be solved quickly, correctly . . . at a big saving in trouble for you!

The word "National" is a registered trade-mark of

NATIONAL CARBON COMPANY, INC.

Unit of Union Carbide UCC *and Carbon Corporation*

GENERAL OFFICES: 30 East 42nd Street, New York 17, N. Y.

DIVISION SALES OFFICES: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

A-C'S BULLETIN BOARD

* POWER USE NEWS *

Costs Cut One-Third By Induction Heating

IN THE BRAZING application shown above, costs for stock and machine time were cut one-third by using A-C's electronic heater instead of the former non-electrical method. Each assembly required just *nine seconds* brazing time!

Besides making possible faster, cleaner brazing, the induction heating method gives accurate heat zone control for heat treating and surface hardening . . . eliminates metal distortion by its rapid application of heat to a controlled depth.

Induction heating is an example of how *increased use of electrical power helps industry make things better, quicker, cheaper—furthers American good living.* Allis-Chalmers offers both vacuum tube equipment (electronic heaters) for high frequency induction heating, and electronic mercury arc converters for economical heating at the lower frequencies. Write today for newest bulletins.

ON ELECTRICAL POWER

* POWER SUPPLY NEWS *

5-Cycle "Ruptor" Gives New System Stability

WHAT IT IS: The 5-cycle "Ruptor" is the interrupting device now employed in Allis-Chalmers outdoor oil circuit breakers rated 115 kv and higher, meeting the new NEMA Standard. It employs the same time-proved principles for limiting arc energy release as does the 8-cycle "Ruptor."

WHAT IT DOES FOR YOU: The new quick-clearing device maintains greater system stability on high voltage lines, and further reduces contact burning and oil carbonization. It assures minimum arc energy release, and low tank pressures.

Exhaustive laboratory tests assure the ability of the 5-cycle "Ruptor", in oil circuit breakers rated up to 3,500,000 kva at 115 kv and higher, to interrupt short circuits from 25 to 100% of rating within 5 cycles after energization of the trip coil.

OTHER DEVELOPMENTS: Ultra-rapid pneumatic operators — now available in Allis-Chalmers outdoor oil circuit breakers rated 15 kv and higher, 500,000 kva and above — reclose breakers within 20 cycles, for improved service continuity on high voltage lines. *For more information on the complete Allis-Chalmers line of outdoor oil circuit breakers, call our nearby district office.*

5-CYCLE RUPTORS for greater system stability are built into these Allis-Chalmers type BZO-60-161H outdoor oil circuit breakers installed at a southern substation.

RUPTOR SHROUD at left, in this photograph of a type BZO-60 oil circuit breaker tank interior, limits arc energy release, thus helping to maintain dielectric strength of oil in tank. A 1934

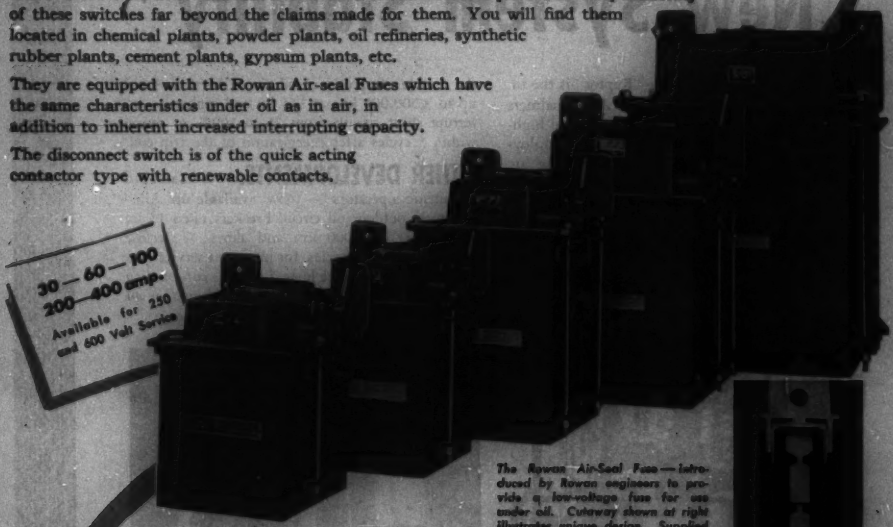
FOR MAXIMUM SAFETY AND CONTINUITY OF SERVICE

Rowan COMPLETELY OIL IMMERSED, FUSED, SAFETY LINE DISCONNECT SWITCHES

Designed and time-tested for locations where the atmosphere is contaminated with corrosive elements, semi-hazardous and hazardous vapors and dust. Continuity of service under these conditions and adverse weather conditions has proved the dependability of these switches far beyond the claims made for them. You will find them located in chemical plants, powder plants, oil refineries, synthetic rubber plants, cement plants, gypsum plants, etc.

They are equipped with the Rowan Air-seal Fuses which have the same characteristics under oil as in air, in addition to inherent increased interrupting capacity.

The disconnect switch is of the quick acting contactor type with renewable contacts.



The Rowan Air-Seal Fuse—introduced by Rowan engineers to provide a low-voltage fuse for use under oil. Cutaway shown at right illustrates unique design. Supplied in 30—60—100—200—400 amp., 250 and 600 Volt.

Other features of the Rowan Oil Immersed Disconnect Switch are:

1—ROWAN AIR-SEAL fuses. **2**—Completely oil immersed. **3**—Disconnect switch of the quick acting contactor type with renewable contacts. **4**—Safety enclosing case mechanically interlocked to prevent lowering of tank when switch is in operating position or closing of switch when tank is lowered. **5**—Enclosing case is weather-resisting and dust-tight. **6**—PROVISION for locking disconnect switch in "off" position. **7**—Tank handles for ease of handling.

The Rowan Controller Company has specialized in Oil Immersed Controls for nearly half a century. Results and performance achieved by users justify the Rowan claim of superiority in this field. Write for complete information on Rowan Oil Immersed Controls.

ROWAN CONTROL

THE TOOL THAT *Connects for Keeps*

Okay . . . continue soldering your small-wire connections, *if you insist.*

But, we believe you'll quickly change to the Indent method of connecting . . . once you have the facts. Here they are:

Indenting Burndy HYDENT connectors with the handy HYTOOL illustrated, will save you time, money, eliminate a messy soldering job, and assure you a perfect connection *every* time. You simply insert the wire into the connector barrel and indent with the HYTOOL. Indenting actually swages the two together, making a permanent connection. *It's the clean way to do a clean job!* Remember, too, that HYDENT connectors are of pure copper one-piece construction . . . further assurance of a strong, low-resistance connection.

Worth investigating, isn't it? Or, if your connection problems involve large cables or large quantities, ask us about the many other HYTOOLS and HYPRESSES. For complete information write today to . . . Burndy Engineering Co., Inc., 107-M Bruckner Boulevard, New York 54, N. Y.

Headquarters for CONNECTORS

Burndy

LONG SCALE, WIDE RANGE VOLT-OHM-MILLIAMMETER

DOUBLE SENSITIVITY
D. C. VOLT RANGES
0-1.25-5-25-125-500-2500 Volts, at 20,000 ohms per volt for greater accuracy on Television and other high resistance D.C. circuits.
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

A. C. VOLT RANGES
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

OHM-MEGOHMS
0-400 ohms (60 ohms center scale)
0-50,000 ohms (300 ohms center scale)
0-10 megohms (60,000 ohms center scale)

DIRECT READING OUTPUT LEVEL DECIBEL RANGES
−30 to +3, +15, +29, +43, +55, +69 DB

TEMPERATURE COMPENSATED CIRCUIT FOR ALL CURRENT RANGES D. C. MICROAMPERES
0-50 Microamperes, at 250 M.V.

D. C. MILLIAMPERES
0-1-10-100-1000 Milliamperes, at 250 M.V.

D. C. AMPERES
0-10 Amperes, at 250 M.V.

OUTPUT READINGS
Condenser in series with A.C. Volts for output readings.

ATTRACTIVE COMPACT CASE
Size: 2½" x 5¼" x 6". A readily portable, completely insulated, black, molded case, with strap handle. A suitable black, leather carrying case (No. 629) also available, with strap handle.

LONG 5" SCALE ARC
For greater reading accuracy on the Triplett RED ● DOT Lifetime Guaranteed meter.

SIMPLIFIED SWITCHING CIRCUIT
Greater ease in changing ranges.

Write for descriptive folder giving full technical details

Precision first ...to last

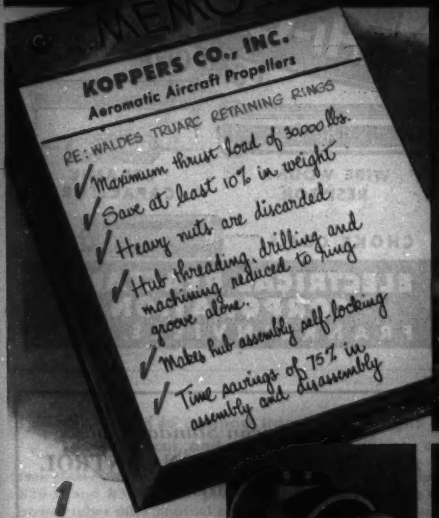
Triplett

STANDARDS ARE SET BY TRIPLETT

ELECTRICAL INSTRUMENT CO. BLUFFTON, OHIO

AEROMATIC AIRCRAFT

WITH WALDES RETAINING RINGS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KOPPERS CO., INC.
Aeromatic Aircraft Propellers
RE: WALDES TRUARC RETAINING RINGS
✓ Maximum thrust load of 30000 lbs.
✓ Save at least 10% in weight
✓ Heavy nuts are discarded
✓ Hub threading, drilling and machining reduced to ring groove alone.
✓ Makes hub assembly self-locking
✓ Time savings of 75% in assembly and disassembly

AEROMATIC AIRCRAFT PROPELLERS are standard equipment on the Rocket 185, illustrated above.

1

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2

AFTER TRUARC—

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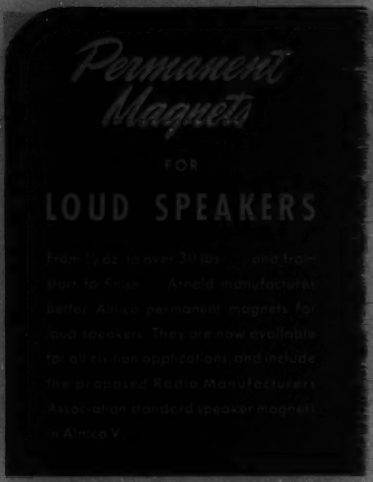

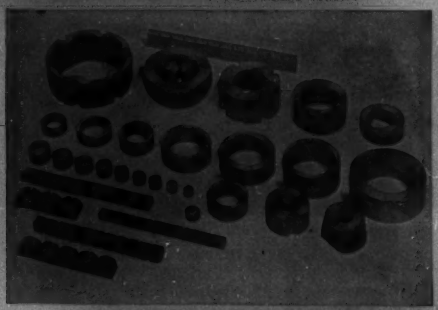

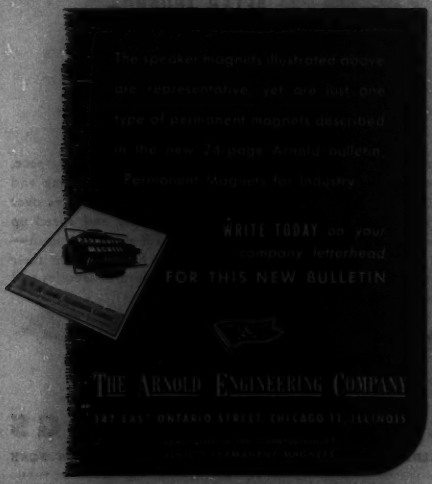

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RCA tube application engineers are ready to consult with you on any design problems you may have involving these or other RCA Electron Tubes. If you wish their services, or additional technical data on these tube types, write to RCA, Commercial Engineering Department, Section D-9B, Harrison, N. J.

COMPARATIVE TECHNICAL DATA
(Plate-Modulated Class C Telephony)

Tube Type No.	Plate Input Watts	Driving Power at Tube	Max. Rating Freq. Mc.	Plate Volts	List Price
2E24	ICAS 27	0.2	125	300	$3.50
2E26	ICAS 27	0.2	125	500	3.20
6C24	CCS 1000	75.0	160	2500	45.00
815	ICAS 60	0.2	125	400	4.50
826	CCS 75	6.5	250	800	12.00
829-B	CCS 90	1.0	200	425	17.00
832-A	CCS 22	0.2	200	425	13.00
8025-A	ICAS 33	1.5	500	800	11.00

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TUBE DIVISION
RADIO CORPORATION of AMERICA
HARRISON, N. J.

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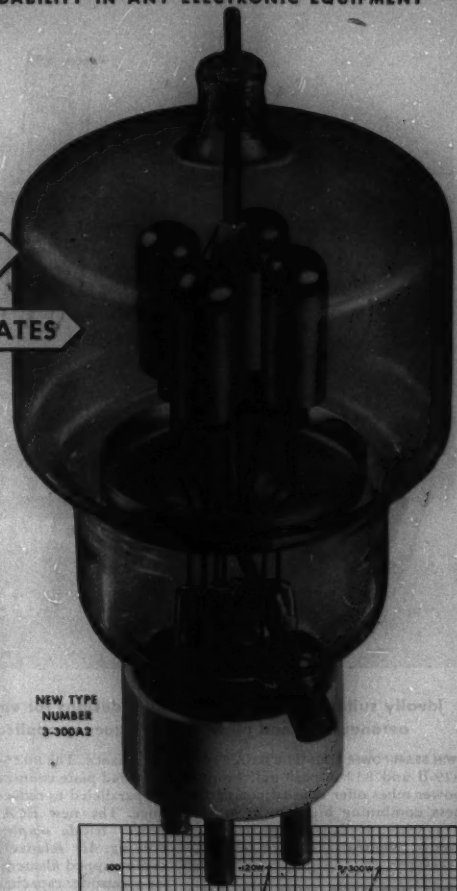


NEW TYPE NUMBER 3-300A2

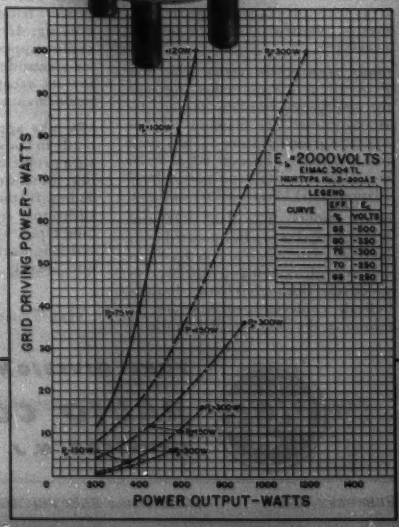
The Eimac Multi-Unit triode 3-300A2 pictured above is a radically improved version of the original 304TL which has been establishing outstanding performance records for a number of years in both civilian and military equipment.

The use of Eimac developed, non-emitting grids, contributes greatly to its already high stability, efficiency and long life, and the new type plates enable it to operate at much lower temperatures.

One of its outstanding characteristics is its ability to handle high current at relatively low voltages. For example: as a class-C amplifier the Eimac 3-300A2 will handle 1200 watts plate input with only 2000 volts on the plate. Under these conditions, the tube will deliver a power output of 900 watts, with a driving power of only 36 watts. The chart at right shows driving power requirements vs. power output. The symbols P_p indicate plate dissipation. Further information will be promptly supplied without cost or obligation.

ELECTRICAL CHARACTERISTICS

Filament: Thoriated tungsten	
Voltage	5.0 or 10.0 volts
Current	25.0 or 12.5 amperes
Amplification Factor (Average)	12
Direct Interelectrode Capacitances (Average)	
Grid-Plate	9.1 uuf
Grid-Filament	8.5 uuf
Plate-Filament	0.6 uuf
Transconductance (I_b=1.0 amp., E_b=3000, e_c=−200)	16,700 umhos



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V. O. JENSEN, General Sales Co., 2616 Second Ave., Seattle 1, Washington. Phone: Elliott 6871.

M. B. PATTERSON (W5CI) ... 1124 Irwin-Keasler Bldg., Dallas 1, Texas. Phone: Central 5764.

ADOLPH SCHWARTZ (W2CN) ... 220 Broadway, Room 2210, New York 7, N. Y. Phone: Cortland 7-0011.

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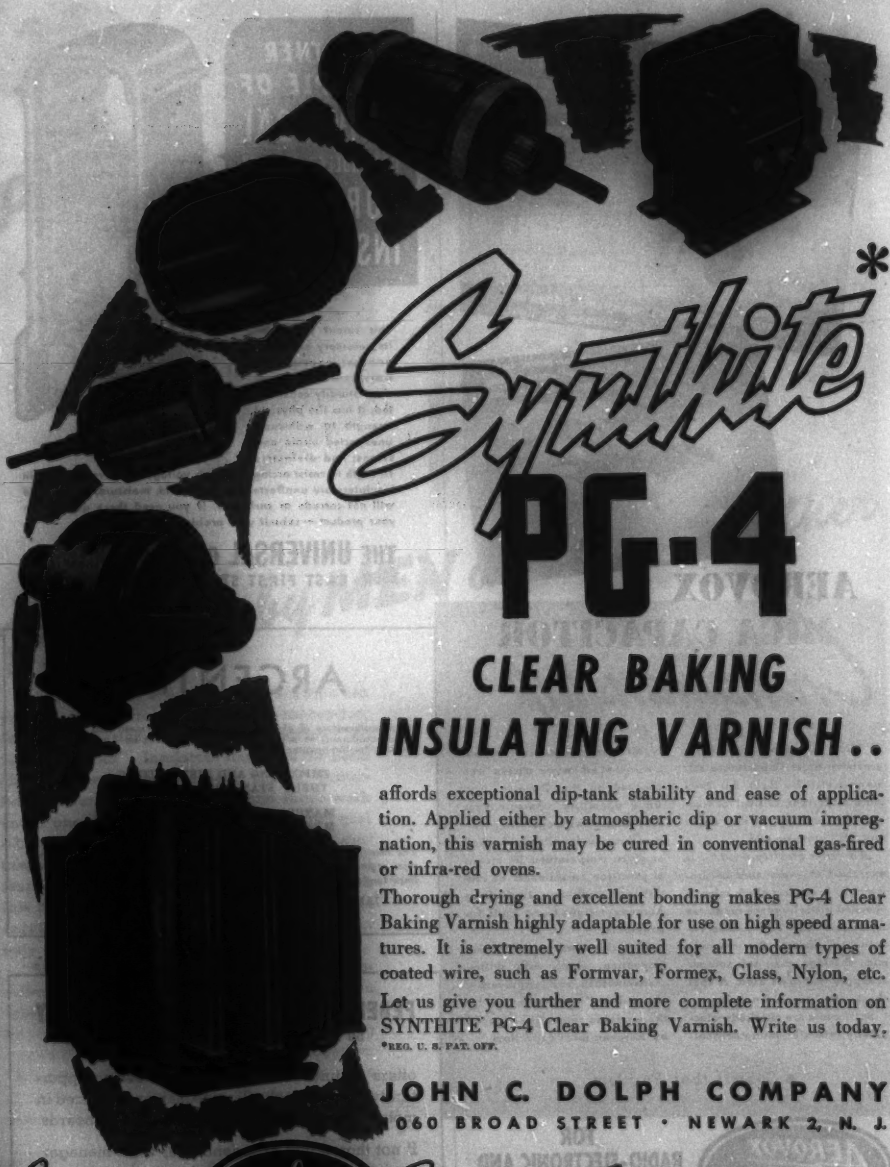

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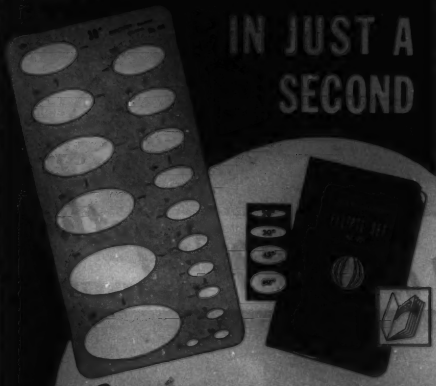

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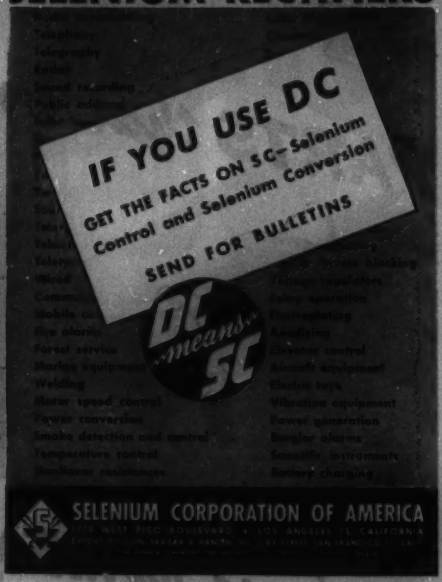

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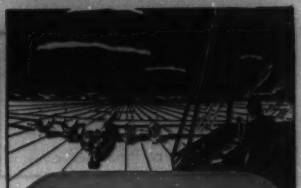

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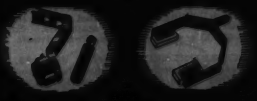

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RESEARCH FELLOWSHIP, half-time, in electronics, as applied to mass spectrometer development. Should have B.S. in E.E. or Physics and either courses in fundamental electronic circuits or some practical experience in this field. It is expected that applicant will devote half time towards studying for advanced degree. Salary, $125 a month. Location, Texas. W-6529.

PHYSICIST OR RESEARCH ELECTRICAL ENGINEER, 32-40, familiar with product design, to take charge of research, material testing and specifications for specialty electrical products manufacturer. Salary, $6000-$8000 a year. Location, western New York State. W-6554.

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Professional Engineering Directory	53
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Reconstruction Finance Corp.	53
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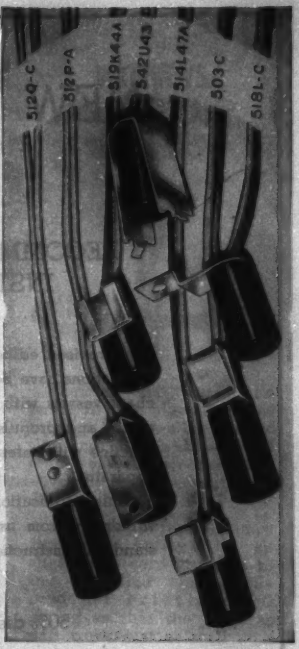

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(Approved June 27, 1945)

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This modification includes all items contained in 45A (War time supplement withdrawn from use) which it has been agreed should be recommended as standard construction, as well as some further developments.

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(Standard Approved for Trial Use June 27, 1945)

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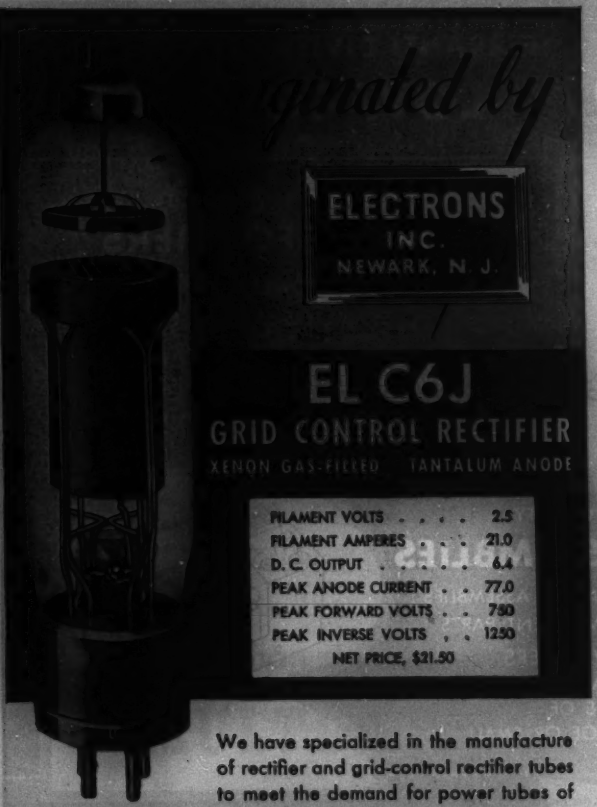

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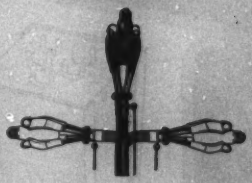

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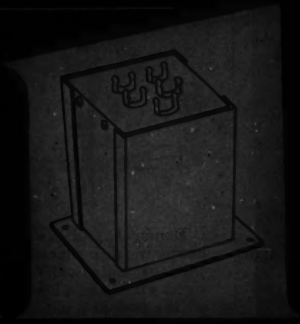

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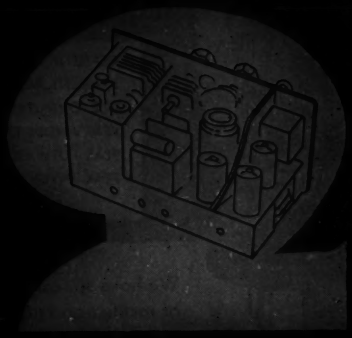

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